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Modeling joint theater level operations in the Early Entry Theater Level Model

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THESIS

MODELING JOINT THEATER LEVEL OPERATIONS IN THE EARLY ENTRY THEATER LEVEL MODEL

by

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September, 1994

Thesis Advisor: S.H. Parry

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This thesis investigates the capabilities of the Early Entry Theater Level Model (EETLM), a modified version of the Future Theater Level Model. It incorporates joint theater level operations within a dynamic decision making framework and a stochastic environment. This thesis includes a rationale of why a stochastic joint theater model is needed, a detailed description of the model's basic operations, and the enhancements and modifications which are required to incorporate joint operations. The development of measures of effectiveness, and their subsequent analysis, focus on the unique perception-based capabilities of EETLM and its ability to provide new insights to joint task force commanders. The analysis focuses on alternative force level/time combinations and their resultant differences in outcomes. Where results appeared counterintuitive, further investigations were conducted. These areas were either analyzed and documented or followed by brief descriptions of required future work for EETLM EETLM successfully demonstrated its capability to incorporate joint theater level operations, however, the analysis indicates that some of the rudimentry algorithms and the current computational platform are limiting EETLM's capabilities.

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MODELING JOINT THEATER LEVEL OPERATIONS IN THE EARLY ENTRY THEATER LEVEL MODEL

by

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ABSTRACT

This thesis investigates the capabilities of the Early Entry Theater Level Model (EETLM), a modified version of the Future Theater Level Model. It incorporates joint theater level operations within a dynamic decision making framework and a stochastic environment. This thesis includes a rationale of why a stochastic joint theater model is needed, a detailed description of the model's basic operations, and the enhancements and modifications which are required to incorporate joint operations. The development of measures of effectiveness, and their subsequent analysis, focus on the unique perception-based capabilities of EETLM and its ability to provide new insights to joint task force commanders. The analysis focuses on alternative force level/time combinations and their resultant differences in outcomes. Where results appeared counterintuitive, further investigations were conducted. These areas were either analyzed and documented or followed by brief descriptions of required future work for EETLM. EETLM successfully demonstrated its capability to incorporate joint theater level operations, however, the analysis indicates that some of the rudimentry algorithms and the current computational platform are limiting EETLM's capabilities.

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EXECUTIVE SUMMARY

A. The principle purpose of this thesis was to demonstrate the capability of the Early Entry Theater Level Model (EETLM) to model joint theater level conflict in a stochastic environment. The focus of this thesis is a proof of principle, not a statistically study. Only a limited numbers of replications were conducted to show the variability in outcome. Additionally, the secondary purpose was to document and test the design of this new stochastic joint theater level model. The simulation scenario will be conducted on the Korean peninsula to support three specific cases of joint operations (early Naval and Marine involvement, late Naval and Marine involvement, joint {simultaneous} Army, Navy, and Marine involvement). This scenario does not permit the investigation of early entry issues, however does permit the investigation of joint reinforcing operations. The Korean scenario was developed originally for FTLM's use, and was the only scenario available for use in a stochastic theater level model. The specific thesis goals are:

1. Build a joint model with air, ground and sea interfaces.

2. Develop a realistic theater level scenario, which exercises the model and ultimately demonstrates the capabilities of the model to represent a joint theater environment.

3. Develop measures of effectiveness to address theater level joint early entry issues, planning, and "what if" analyses.

4. Develop measures of effectiveness to assess the impact of joint operations.

5. Identify areas where there are potential model validity problems.

B. The following issues were investigated within the scope of the this thesis' overall purpose and goals.

1. Impact of Course of Action (COA) Perceptions on Joint Operations.

    a. Perception Changes Over time.

    b. COAs chosen.

    c. Impact of time.

2. Timing of the decision to commit Joint Early Entry forces.

3. Preposition afloat.

4. Usefulness of EETLM to the Joint Task Force (JTF) Commander

    a. In the planning phase of the operation.

    b. Enroute to the theater of operation.

    c. The time phased strength levels (combat effectiveness levels) of all units.

C. To specifically address the above issues, the measures of effectiveness listed below were developed.

1. Force Remaining Ratio for both sides.

2. Loss Exchange Ratio.

3. Theater Campaign stopping rules.

a. Did Red reach its objectives (all or some)?

b. Did a side reach its breakpoint?

4. Blue's perception of Red's COAs, given Red is conducting a specific COA.

5. Red's perception of Blue's COAs.

6. Blue's perception of Red's attack time.

7. Blue decision (time) for when to commit reinforcing forces.

D. Snapshots of the simulation were taken at these times to obtain all the requisite data requirements to satisfy the MOEs.

1. STARTEX: the start of the simulation.

2. ATTACK TIME

3. PERCEIVED ATTACK TIME

4. EVERY COA UPDATE CYCLE

5. SURFACE-TO-SURFACE ENGAGEMENTS

6. ENDEX: the termination of the simulation.

E. A notional scenario, focused around the defense of the Korean peninsula, was used as the major regional contingency (MRC). The scenario called for a massive Red attack from the north, and a defensive response from Blue. Blue responded in one of three ways: an early arrival of joint forces; a late arrival of joint forces; and an on time arrival of joint forces. Blue's response was pre-determined by the author to capture the differences between entry cases. Red's selection of COA was determined by the analyst; however, Blue's COA was dynamically determined, within the entry case, by the model.

There were three Red COAs developed, and all three were used against all Blue entry cases. A total of twenty seven replications were run; three replications for each of the three Red COAs against each of the three Blue entry cases. Because the prototype model is not fully mature, complete statistical analysis using large number of replications is not appropriate for this thesis. The results of the various combinations of Red COA and Blue entry case were analyzed and it was concluded that: EETLM possesses the capabilities to model joint theater level operations in a stochastic environment. The current limitations imposed by the rudimentary algorithms and the computational platform prevent EETLM from providing intuitive results. The final chapter in this thesis recommends areas for future improvement of the model.

I. INTRODUCTION

A. PURPOSE OF THESIS

The goal of this research paper is to investigate the capabilities of the Future Theater Level Model (FTLM) to answer real world questions that have arisen from the new world order. Specifically, this thesis examines FTLM's capability to provide the U.S. Army Training and Doctrine Command (TRADOC) and the Early Entry Lethality Survivability (EELS) Battle Lab with meaningful results and analysis which address the timing of joint forces and the impact of varying the sizes of forward deployed forces. Also, this thesis investigates FTLM's capability of providing an early entry Joint Task Force (JTF) commander with valuable feedback about his operation in the planning phase and while enroute to the theater. This thesis will use a modified version of FTLM, the Early Entry Theater Level Model (EETLM), to investigate these capabilities.

B. PROBLEM STATEMENT

Given a scenario, a joint task force, and EETLM:

Can EETLM adequately incorporate Joint forces and model the conduct of Joint Operations?

Other questions that will need to be answered, in support of this question are:

Is EETLM sensitive to the impacts of time and variations in joint early entry force sizes?

Can these impacts be incorporated in the analysis?

Once EETLM has matured completely, and demonstrated its capabilities to model joint theater level operations, a critical question which can be explored is: What are the required force sizes of forward deployed units? This question will be left for future work; however, some of the methodology discussed later is applicable. The reader is referred to the Methodology (Chapter III) for a more detailed explanation of these and other questions.

C. SCOPE OF THESIS

In light of the draw down and the substantial budget cuts across all of the Armed Forces, the analysis and results of these questions are of critical importance. The U.S. Army Training and Doctrine Command (TRADOC), in particular, and the Army, in general, are looking for ways in which to economize, yet still have the requisite force projection capabilities. Joint operations are a viable way to accomplish this task. [Ref. 1, pg. 3-1] EETLM possesses the ability to model joint operations, to simulate some of the conditions of uncertainty found in the new world order, and provide results and analysis of joint operations. EETLM is a stochastic combat simulation model being developed at the Naval Postgraduate School. The model focuses on perceptions which are dynamically generated from sensor/intelligence reports. The ensuing actions in EETLM are taken based on those perceptions. EETLM has been enhanced to incorporate joint operations (Army, Air Force, Navy, and Marines), perception on both sides and on all node types (the ground representation is an arc - node network), dynamic Course of Action (COA) selections based on perceptions, and substantially larger force sizes. This thesis will use EETLM to examine the impact of response times of joint forces (Navy, Marine, Air Force, and Army) within a notional major regional conflict. The simulation scenario will be conducted on the Korean peninsula to support three specific cases of joint operations (early Naval and Marine involvement,

late Naval and Marine involvement, joint {simultaneous} Army, Navy, and Marine involvement). This scenario does not permit the investigation of early entry issues, however, it does permit the investigation of joint reinforcing operations. The Korean scenario was originally developed for FTLM's use and was the only scenario available for use in a stochastic theater level model. In the scenario, the Red forces will be the aggressors and attack from the north. The Blue forces will not initiate aggression, but will defend the south. The thesis will investigate the sensitivity of EETLM to variations in joint capabilities and response times. The sensitivity analyses will focus on perceptions of courses of actions, time phasing of forces, and joint operations for both enemy and friendly forces. Navy LT Michael Fulkerson and this author developed the joint capabilities and scenario for EETLM. LT Fulkerson's thesis analysis focuses on the naval aspect of the model whereas this thesis focuses more on the ground aspects of the operations. The reader is referred to LT Fulkerson's thesis for the specific naval details. [Ref. 2]

D. BACKGROUND

The Naval Postgraduate School was initially tasked to develop a stochastic theater level model by the Force Structure, Resource, and Assessment Directorate (J8) of the Joint Chiefs of Staff. Within J8, the Analytical Tools Program mission statement required them to:

> Apply operations research to address assessments of conventional forces capabilities, such as: ...Examining large-scale ground and air conflict at the theater level by comparing the significance of alternative force sizes, structures, and mixes." ... "Provide support to the unified and specified commands outside the Joint Staff, such as: ... Supporting joint force capability assessment through representation of land, sea, and air combat. [Ref. 3]

Since the initial model development at the Naval Postgraduate School, TRADOC has also become a participant in the development of the model. The Naval Postgraduate School, Office of

the Deputy Chief of Staff for Combat Development, Office of the Deputy Chief of Staff for Doctrine, and the Louisiana Maneuvers Task Force have entered into an agreement to adapt the FTLM architecture to solve doctrinal problems of interest to TRADOC, specifically in operations other than war and joint operations. One of the primary missions of TRADOC is to develop training and doctrine to support the missions of today's Army and for the future. The design of doctrine for operations other than war and the evaluation of joint doctrine, organizations, and materiel have been identified as significant issues facing the Force Projection Army. TRADOC has determined that existing models such as TACWAR, CASTFOREM, VIC, and other models are not adequate to represent these operations. [Ref. 4] General Franks stated, "rewickering of existing models won't work. We need a new set of models to examine the changing missions and threats." [Ref. 5] This model has been demonstrated and briefed to General Franks, Commanding General, TRADOC and to the Board of Advisors of the Naval Postgraduate School.

E. THESIS ASSUMPTIONS

The following assumptions are made for this initial version of EETLM:

- It is assumed that EETLM contains all relevant, true, and viable Courses of Action, (COAs). The implication of this assumption, (the closed world assumption) is that any other COAs not present or represented in EETLM are therefore assumed to be false, irrelevant, and/or not viable. [Ref. 6, pg. 177] A method of including other nonspecific COAs and the benefits associated with their incorporation will be discussed in Chapter VI.
- The basic combat maneuver units are Infantry, Armor, and Mechanized, only.
- Divisions, or Groups normally operate with three to four Brigades (Bdes).

- Intelligence capability exists (HUMINT, SIGINT, JSTARS) to obtain an accurate count of the numbers of Bdes in a Division or Group.

- A massive logistical build-up, forward, is an indicator of an impending attack. A massive logistical build-up is defined as sufficient logistical supplies to support the perceived total number of brigades required in combat for one week.

- All the unit data such as size, configuration, combat power, strength, locations, logistic strength and consumption rates, and other tactical elements have been formulated to keep this work unclassified. However, the ideas, principles, questions, and answers can be used in classified scenarios where appropriate.

F. THESIS LIMITATIONS

The following limitations exists in this version of FTLM:

- This thesis uses a Korean scenario which permits the evaluation of joint forces in a reinforcing role, not in an early entry role. The scenario also permits the evaluation of the timing of the reinforcement. However, this scenario is not an early entry scenario.

- The model has not undergone any rigorous validation. Once the model matures, validations of all algorithms will take place. All the algorithms are mathematically sound; it is the translation into computer code which must be validated to insure accuracy.

- At the start of the simulation, until the first COA update, the initial perceptions of each COA, expressed in probabilities, are all equally likely. This is somewhat unrealistic, but in the mature EETLM, the analyst will be able to input initial COA perceptions, which are not equally likely.

- The number and size of forward deployed units is held constant.

- The division force sizes (number of brigades) are limited to a maximum of four combat brigade units.

- A division can be composed of any combination of combat brigades (Bdes), totaling four.

- Once a COA is chosen by the attacker or defender, it remains fixed. Currently, there is no way to dynamically shift COAs in mid-simulation. Future developments for FTLM should include the ability to dynamically reallocate COAs during a simulation replication.

- The ground arc - node network is restricted to a maximum of two transit nodes between any two physical nodes. This limitation exists in the current hardware and software configuration and it is due to the computational complexity involved when calculating the Bayesian perception updates associated with each node (both physical and transit) and each permutation.

- No more than one Division, or Group, of the same side is allowed on a node (physical or transit) at any one time, because EETLM currently cannot differentiate between the two different divisions, or groups. As a result, the model attempts to determine the probabilities of the possible permutations of the larger composite group, and this becomes too computationally intense. This limitation is discussed in more detail in Chapter VI.

- EETLM does not allow for node partitioning within a node. Therefore, once a unit occupies a node, its sub-units cannot be assigned individual sectors or orientations within the node itself. This feature will be added in future versions of the model.

- EETLM has the ability to conduct sensor observations after a unit detection, on both transit and physical nodes. EETLM automatically conducts sensor observations after each unit detection on a transit node, but does not do so on physical nodes, because of the computational

complexities involved. To allow for some sensor observations on physical nodes, the physical nodes were divided and packaged into sensor groups. The frequency of the sensor observations was dependent upon the priority the sensor group.

- Currently, a perception link between air activity (CAS, BAI) in support of a ground COA, and the actual ground COA does not exist.

- Naval power projection (i.e., Naval Surface Fire Support (NSFS), Tomahawk and carrier based air) is scripted and is not dynamically linked to the ground COA. A perception link between Naval support and the actual ground COAs does not exist.

- There is limited Air Force and Air Defense Artillery capabilities on both sides. EETLM has a total of two air bases (one for each side). Blue has two squadrons: one F-16 squadron and one F-15 squadron, Red has four squadrons: two each of MIG-23 and SU-25. Each side also only has two divisions with ADA capabilities.

Most, if not all of the limitations noted above are due to the computational limitations imposed by the platform and software structure of the current model. As the model matures, it will be transported to a platform with much greater capabilities, so that the computational complexities will not be a limiting factor.

G. THESIS FORMAT

1. Chapter I

The purpose, scope and background of this thesis have been presented.

2. Chapter II

This chapter of the thesis discusses the motivation behind the development of FTLM. This discussion includes the impact of the new world order, the uncertainties inherent in combat,

and the problems associated with existing theater level models. A detailed description of the current state of FTLM is presented, which focuses on the command, control, communications, and intelligence (C^3 I) and the detection and fusion processes. The final portion of this chapter outlines the development of EETLM. The focus is primarily on the new algorithms, the joint capabilities, and the scenario.

3. Chapter III

Chapter III provides a methodology for addressing the thesis problem statement in Chapter I. The problem statement is decomposed into issues for investigations which are further refined and quantified into measures of effectiveness (MOE) and data requirements. A data source matrix is provided to identify which data requirements will be used to satisfy MOEs and issues. Critical simulation events for data collection are identified and described. The method for analysis of the data and MOEs are also described.

4. Chapter IV

Chapter IV discusses the results and analysis of the test replications. The analysis is discussed in two parts. The first part is the traditional MOE analysis, which is followed by the perception analysis. The goal is to address the issues, and by doing so, demonstrate the capabilities of EETLM in modeling joint theater level operations. Some of the results indicate current shortcomings with the prototype EETLM. One of the purposes of this thesis was to discover these problems for future model enhancements. Therefore, the reader should focus on the type of analyses possible using EETLM rather than the specific numerical results from the current prototype.

5. Chapter V

From the analysis in Chapter IV, conclusions will be drawn and recommendations made concerning EETLM.

6. Chapter VI

Future work for EETLM is suggested in this chapter, based on the problems encountered with the current capabilities that were developed for EETLM, and future capabilities which must be included in the mature model.

II. FTLM ARCHITECTURE

A. MOTIVATION

FTLM was developed to provide a more realistic approach to handling new operations. FTLM's approach does not revolve around the classical European scenario and ground truth, but rather, around perceptions, uncertainties of war, surprise, and command, control, communications, and Intelligence (C^3I). It provides the decision maker with an explicit representation of the variability of the outcomes, given certain input conditions, without causing analytic chaos. This chaos is sometimes produced in deterministic models when dependent, or inter-related input parameters are varied. FTLM also has the added benefit of having reduced size, portability, and easy database and scenario setup. It is a closed form simulation, which allows for repeated replications, ease of experimentation, and multiple excursions to determine cause and effect relationships. All decisions and actions taken within FTLM are based on perceptions generated from dynamic intelligence reports, not ground truth. The perceptions and intelligence reports are fused in a C^3I process which generates decisions. The structure of the model is network based and supports nonlinear ground and sea movement and dynamic air movement. These major development objectives make FTLM unique and suitable to aid in doctrinal design and evaluation of new operations and concepts. [Ref. 7]

1. New World Order

The new world order began with the disintegration of the Soviet Union and the Berlin Wall. These events caused a destabilizing effect in the world. When there were two superpowers, most second and third world countries were aligned with one power or the other.

The alignment guaranteed them military security in exchange for political compliance. Therefore, the United States had to concern itself primarily with the Soviet Union. However, since there are no longer two superpowers, the second and third world countries, who had aligned themselves with the Soviet Union, no longer have that military security by virtue of their alignment and no longer have to comply politically or militarily with anyone. As a direct result, the United States must concern itself with numerous second and third world countries whose behaviors are totally unpredictable and, at times, completely irrational. This makes for an extremely uncertain world in which the old rules of politics, combat, and influence no longer apply.

2. Uncertainty of Combat

Very few things in the world are certain. Most things having varying degrees of certainty associated with them. Combat, almost by definition, is uncertain. No one can predicted with complete accuracy who will win, and why. There are many factors which are indicators of the possible success of one side over another, but these indicators cannot be quantified and predicted with enough accuracy to allow combat to be certain. Human factors, such as dynamic leadership, bravery, loyalty, training, fatigue, and morale, are among a few such indicators. Even if these indicators could be quantified, the degree to which each factor would impact on any given event would vary. Historical studies have shown that these factors are indicators and not absolute predictors. It does not make sense to attempt to model future combat without considering uncertainty. Force sizes, structures, composition, intelligence, new tactics, and new weaponry are a few of the uncertainties which must be incorporated into combat simulation models. Clearly, combat is not understood with enough detail. Those factors that are understood cannot be quantified sufficiently to make certain predictions of outcomes. These uncertainties make

predicting combat outcome problematic, and tend to indicate that modeling combat should be done using some sort of a stochastic process. [Ref. 8]

3. Existing Models

Recent studies and research have indicated that the current theater level model, TACWAR, is not adaptable for new world type operations. [Ref. 4] Most existing models (i.e., TAC THUNDER, CEM, FORCEM, VIC, EAGLE, TLC/NLC, SOTACA, and WARSIM/NASM) are either deterministic in design, use methodologies based on ground truth, are designed to support a European battle, or have poor, or no C^3I integration. These models do not possess the required analytical tools necessary to model today's new world order. [Ref. 7]

a. Deterministic Design

Any model which does not contain probabilities, or random effects, is a deterministic model. Stochastic models use probability distributions, over the sample space of possible outcomes to model the uncertainties of the real world and combat. [Ref. 9, pg. 3] The previously mentioned existing models can be characterized as low resolution, highly aggregated, and depicting combat as a deterministic phenomenon. In general, the outcomes can be abnormally sensitive to minor input changes which can produce chaotic results. The results do not account for any measure of uncertainty in the output, given uncertainty in the inputs. [Ref. 8] The methodology of depicting combat as a deterministic phenomenon is intended to provide the expected results of combat. However, even when averages are used as inputs, the outputs are not necessarily representative of mean, or average outcomes of combat. The U.S. Army Concepts Analysis Agency, (CAA), in August 1991, found that most of the results (point values) produced by deterministic models were noticeably different from the expected values produced by

stochastic models. Some of the results fell outside of the range of results produced by the stochastic models. [Ref. 10] CAA also found that these results were statistically significantly different. [Ref. 11] Further, if we consider this result as an extension of Jensen's Inequality (from one variable to the n variables associated with a combat model), the reader can appreciate why averages used as inputs do not produce average outcomes. Jensen's Inequality is as follows:

$$f[E(X)] \leq E[f(X)] \qquad (1)$$

The Jensen's Inequality states that if a convex function is applied to an expected value (or average) the result will be less than, or equal to, the expected value of all the results produced by the convex function from the input values used to produced the original expected value. The inequality is reversed if f(X) is a concave function. Only when the function is linear does the strict equality hold. Intuitively, if there exists variance in the outcome of a random variable ($\mathrm{Var}(X) \geq 0$and $\mathrm{Var}(X) = E(X^2) - [E(X)]^2 \geq 0$) then it is obvious that $E(X^2) \geq [E(X)]^2$. [Ref. 12, pg. 298]

b. Command, Control, Communications, and Intelligence

In the past, most of the theater level models focused on the terrain representation, the attrition process, and ground truth orientation. The C^3I process was not emphasized because the scenarios, battlefields, initial positions, boundaries, force sizes, force structures, objectives, and doctrine were well studied and defined. These types of models portray massive attrition battles fought in Corps sectors with distinct FEBA movements. The need to analyze decisions was minimal, since both sides knew unit locations, sizes, strengths, capabilities, and COAs with relative certainty. [Ref. 13] Some of the later models have attempted to incorporate a C^3I process, but almost as an afterthought. [Ref. 8] Such precise and perfect intelligence is not a luxury afforded the real world. Models which use the ground truth methodology cannot

incorporate an adequate C^3I process capable of representing the frailties, contributions, and dynamics of operational C^3I. Surprise, envelopments, feints, and deception cannot be modeled in these types of environments.

B. CURRENT MODEL

1. Analytical Structure of FTLM

Analytical solutions of symbolic models use explicit mathematical formulas to obtain output variables, as a function only of input variables. These analytical solutions are derived by manipulating mathematical formulae and applying mathematical rules to obtain the desired outcome. These outcomes are favorable because they establish direct relationships between inputs and outputs (cause and effect). FTLM is a symbolic model. The main characteristics of FTLM are its stochastic and dynamic nature, high information flow, and aggregation. The symbolic nature of FTLM, in conjunction with simulation, numeric, and analytical solution methods, allows it to deduce solutions which are useful to military decision makers.

The solutions obtained by FTLM will either be an explicit formula for a probability distribution, or summary statistics (i.e., mean and variance) of the output available. One of the major modeling objectives of FTLM is to capture the variability of performance measures, not just the mean values. The numeric solutions will be derived by mathematical manipulations and simulation. Additionally, sensitivity analyses can be conducted with this output by analyzing the differences in the distributions produced, or summary statistics. [Ref. 14, pg. 23-24]

2. Environment of the model

The model's environment is an arc - node network system. Two arc - node networks, a ground and an air network, accommodate all ground and air movement within FTLM. This movement includes the movement of combat units, logistical units and, aircraft. [Ref. 14, pg. 24]

a. Ground Network

In the ground arc - node network, the arcs are referred to as transit nodes and the nodes are referred to as physical nodes. Physical nodes represent geographic locations such as cities, key terrain, objectives, intersections of avenues of approach, or defensive positions. A transit node connects physical and/or other transit nodes together. A transit node has four attributes used to model the terrain between node types. The four attributes are distance, road classification, width of the mobility corridor, and terrain classification which includes severity of terrain and obstacles. Transit nodes represent mobility corridors, avenues of approach, or movement routes. Units do not actually move along transit nodes, rather, they occupy transit nodes. The time spent in the transit node is stochastically determined, based on the attributes of the specific transit node, unit size, type, and mission. Time spent on physical nodes works the same way, unless missions dictated otherwise. On both node types, sensor observations can be taken and fused in the C^3I process to update intelligence (such as unit sizes, location, and most probable enemy COA) and make decisions. [Ref. 14, pg. 25-28]

b. Air Network

A different network system exists within FTLM to support air operations. A square grid system is overlaid on top of the ground network (theater of operations). The grid sizes can be modified to support specific scenario requirements. [Ref. 14, pg. 28] The air module

is composed of three distinct sub-models. Model I uses the air grid network and facilitates the calculation of the percentage of coverage (both actual and perceived) a ground unit's air defense systems has on specific air grids. Model II allows each side to use its perceived coverages to determine ingress and egress routes for all possible air missions. Model III of the air module prioritizes targets and mission capable aircraft, and then optimally selects a combination of targets, number and type of aircraft and routes to carry out all air missions. [Ref. 15]

3. Command, Control, Communications, and Intelligence

a. Unit Movement

Ground units move along the network using a minimum cost algorithm, which considers the shortest distance, perceived enemy locations, and tactical difficulty to move from node to node. If it is tactically prudent, a unit will divide into sub-units and travel along different transit nodes to reunite, or conduct an attack at another physical node. This may be done to achieve surprise or expedite movement. If two or more units on opposing sides occupy the same physical node at the same time and detect each other, close combat may occur. On physical nodes, combat will be adjudicated as a hasty or deliberate attack of one unit on a defending unit. The unit occupying the physical node first will be the defender, and, depending on the length of time before the attack, will be in a hasty or deliberate defensive posture. On transit nodes, combat is adjudicated as a meeting engagement if both forces expect to make contact with an opposing force, or both sides do not expect to make contact, but happen to make contact, unexpectedly. If one side expects to make contact and the other side does not, combat is adjudicated as an ambush. [Ref. 14, pg. 30]

b. Planning

FTLM's planning module contains a series of algorithms which allow each side, when making decisions, to use its perceptions of opponent's COAs and status to conduct "play ahead" enumerations of its possible actions. The algorithms compute potential payoffs associated with each alternative action. The planning module then selects the best alternative action to accomplish the mission. Currently, the planning module is used to determine unit movement routes along assigned corridors, whether or not a unit should divide into sub-units during movement, whether or not a unit should attack a perceived enemy and from which direction, and whether or not a unit should subdivide during the conduct of its attack. The module's algorithms consider perceived combat power, level of C^3I, rates of fire, surprise, and force ratios when making decisions. [Ref. 14, pg. 30-43]

c. Detection and Fusion

All units are subject to detection on all transit nodes from enemy sensors. The time to detection is determined by a random draw from an exponential distribution. Once a unit occupies a transit node, the time to detect is drawn and then an opposing sensor is allocated to make a sensor observation (counts of assets). The sensor capability and accuracy are determined by the user, when sensor data are entered into the database. Through a series of Bayesian updates over time, the detection of units, by asset counts, leads to the determination of perceived unit types, sizes, strength, capabilities, locations, and overall courses of action. These perceptions are used to make decisions in FTLM for movement routes, air mission allocations, ground attacks, deep strikes, and COA selections. [Ref. 14, pg. 43-70] Each side determines the most likely COA its opponent will use by the following method. There are three types of perception updates that

need to be considered: Type 1 is a COA perception update when there have been no detections on any avenues of approach within the COA update period; Type 2 is a COA perception update when there have been detections on all avenues of approach within the COA update period; and Type 3 is a COA perception update when there have been detections on some of the avenues of approach, but not all. In a Type 1 COA perception update, for each side and for every COA update cycle, EETLM runs a mini simulation within the EETLM simulation to enumerate the possible next moves of all opposing units. These next moves will be referred to as the moves which occur in the (K+1)st period. The enumeration has been limited to a specific number (R=20 enumeration replications), because of the computational complexity involved. Over these R replications, an aggregated mean detection rate, $\hat{\lambda}_i(k;r)$, over the entire corridor for period K to K+1 is calculated using equation 2:

$$\hat{\lambda}_i(k;r) =_{j \in J(k)} \sum [\lambda_j(k)] \left[e(k;r)_{ji} \right] [U_{ji}(k)] \qquad (2)$$

where $\lambda_j(k)$ is the rate of detection prior to the K+1 period, r is the rth exposure time realization, $e(k;r)_{ji}$ are all nodes that have a nonzero exposure time during period K, and $U_{ji}(k)$ is the weight by the appropriate exposure times across all possible COAs (C_i) and by units sizes that appear on arc/nodes j for C_i.

The aggregated mean detection rate, $\hat{\lambda}_i(k;r)$, is then used to compute the probability of zero detections, D(k)=0, for a specific COA, (C_i), using the following Poisson probability distribution:

$$P\{D(k) = 0 | C_i, r\} = \frac{1}{R} \sum_{r=1}^{R} e^{-\hat{\lambda}_i(k,r)} \qquad (3)$$

. The probability of at least one detection, $D(k) \geq 1$, for a specific COA, (C_i), is

$$P\{D(k) \geq 1 | C_i, r\} = \frac{1}{R} \sum_{r=1}^{R} \left(1 - e^{-\lambda_i(k,r)\Delta}\right) \tag{4}$$

The probability of at least one detection for a specific COA (C_i) is multiplied by its prior COA probability, and normalized over the sum of the other COAs (multiplied by their respective probabilities of at least one detection) to obtain the posterior COA probability for that specific COA. Equation 5 is used to calculate the likelihood of a specific COA being used in a Type 1 situation, when there are no detections on any avenue of approach.

$$\pi(C_i, K+1) = \frac{P\{D(k) \geq 1 | C_i, r\} \times \pi(C_i, K)}{\sum P\{D(k) \geq 1 | C_i, r\} \times \pi(C_i, K))} \tag{5}$$

Range of summation?

where $\pi(C_i, K)$ is the prior probability for COA C_i and $\pi(C_i, K+1)$ is the posterior probability for COA C_i.

In a Type 2 COA perception update, where there are detections on all avenues of approach, a least squares estimate of the number of assets of type j at node N_n based on the latest detection is given by

$$\hat{A}(n, j, k) = \left\{\sum_{l=1}^{b_n} \frac{s_l(nj, k)}{\sigma_{nj}^2(l)}\right\} \div \left\{\sum_{l=1}^{b_n} \frac{1}{\sigma_{nj}^2(l)}\right\} \tag{6}$$

where n is the number of nodes, $s_l(n,j,k)$ are sensor observations of assets of type j at node N_n during time period $(k\Delta, (k+1)\Delta)$, and σ_{nj}^2 is the variance of the error of the sensor observation. The number of assets of type j at a node, during the time period, can be interpreted as a normal distribution with mean, $m_{nj}(k)$, computed by

$$m_{nj}(k) = \left[\sum_{l=1}^{b_n} s_l(n, j, k) \div \sigma_{nj}^2(l)\right] \div \left[\sum_{l=1}^{b_n} \frac{1}{\sigma_{nj}^2(l)}\right] \tag{7}$$

and variance

$$v_{nj}^2(k) = \frac{1}{\sum_{l=1}^{b_n} \frac{1}{\sigma_{nj}^2(l)}} \tag{8}$$

The results of all sensor observations during the period $(k\Delta, (k+1)\Delta)$, is a distribution of the total number of assets of type j at all the nodes in J(α,k), where J(α,k) is the collection of all nodes that might be occupied during the period, for a specific avenue of approach α. The distribution is normal with mean:

$$\hat{m}_j(\alpha, k) = \Sigma_{N_n \in J(\alpha,k)}\, m_{nj}(k) \tag{9}$$

and variance

$$\hat{v}_{nj}^2(k) = \Sigma_{N_n \in J(\alpha,k)}\, v_{nj}^2(k) \tag{10}$$

A particular COA, C_i, has a distribution of the total number of assets of type j at nodes $N_n \in J(\alpha, k)$ on avenue of approach α, during the time period $[k\Delta, (k+1)\Delta], \hat{A}_j(\alpha, k)$:

$$P\left\{\hat{A}_j(\alpha, k) \in da | C_i = c_i\right\} = \xi\left[a, \mu_j(\alpha, k; c_i), \sigma_j^2(\alpha, k; c_i)\right]da \tag{11}$$

where $\xi\left[a, \mu_j, \sigma_j^2\right]$ is the normal density function with mean = μ and variance = σ^2. The mean is obtained from the TOEs for the numbers and types of units using avenue approach α for a specific COA, C_i. The COA perception is updated as follows:

$$\pi(c_i, k+1) = D\pi(c_i, k)\Pi_{\ \alpha}\Pi_{\ j}\int \xi\left[\alpha, \mu_j(\alpha, k, c), \sigma_j^2(\alpha, k, c)\right]\xi\left[a, \hat{m}_j(\alpha, k), \hat{v}_j^2(\alpha, k)\right]da$$

$$= D\pi(c, k)\Pi_{\ \alpha}\Pi_{\ j}\xi\left[\hat{m}_j(\alpha, k), \mu_j(\alpha, k, c), \hat{v}_j^2(\alpha, k) + \sigma_j^2(\alpha, k, c)\right] \tag{12}$$

where Π is the product taken over all avenues of approach and for all asset types, and D is a normalization constant.

In a Type 3 COA perception update where there have been detections on some of the avenues of approach and zero detections on others, the COA perception is updated as follows:

$$\pi(c_i, k+1) = \frac{\pi(c_i k) P_0(c_i \alpha)[1 - P_0(c_i \beta)]}{\sum_{c=1}^{l} \pi(c_i k) P_0(c_i \alpha)[1 - P_0(c_i \beta)]} \tag{13}$$

where $P_0(c_i\alpha)$ and $[1 - P_0(c_i\beta)]$ are the probabilities of zero detections in the set of avenues of approach α and at least one detection in the set of avenues of approach β, respectively. [Ref. 16]

Currently, FTLM uses sensor observations to calculate the probabilities associated with a Group's (Division) composition (in terms of numbers and types of brigades out of the total brigade types available). The observations are then used to determine the COA perceptions as discussed above. For example, in COA1.NET [Ref. 14], the total number of brigades in the scenario for Blue forces are five brigades (three Infantry, two Armor, and zero Mechanized; {3,2,0}). If a sensor identifies a Group that has a composition of {2,2,0} (for example Group.1-1 [Ref. 14]), there would be twelve possible brigade compositions associated with it.

The probabilities are then calculated for each possible composition as determined by the sensor observation. In this example, Group1-1 has a composition of {2,2,0} and we would expect to see a higher probability associated with this possible composition than with the other eleven. However, this may, or may not be true, depending on the accuracy of the sensor observation. This method of determining the possible compositions of units and associated probabilities is adequate as long as the total number of brigades in any force does not exceed five

or six. When there are more than a total of six brigades in a force, the number of possible compositions of brigades becomes unmanageable.

d. Attrition

The attrition model currently incorporated in FTLM is very rudimentary. The designers of FTLM felt that the attrition results of theater level combat should not be the primary concern of the model. The emphasis of FTLM lies in the implementation of the algorithms dealing with planning, perception, C^3I fusion, surprise, and air - ground linkage. However, a new FTLM version is being developed at George Mason University which has incorporated the ATCAL - COSAGE attrition process, a more sophisticated attrition model. [Ref. 17]

The initial attrition model in FTLM focused only on ground-to-ground and deep strike attrition. The attrition model used a logarithmic function to adjudicate ground force-on-force combat, and an exponential function to adjudicate deep strike attrition. These functions were chosen for the initial attrition model in FTLM because they were computationally simple, and produce somewhat realistic results. Logistics, supplies, and equipment are not attrited, however, they are consumed. The function for supply depletion is based on the using unit's rate of fire, combat power, and logistical strength. C^3I attrition is not currently incorporated into the attrition model, but will be incorporated in the future. [Ref. 14, pg. 82-85] Subsequent versions of FTLM have included more attrition effects. Currently, FTLM has ground-to-air and air-to-ground attrition. In the next version of FTLM, air-to-air attrition will be incorporated. [Ref. 18]

C. EETLM: MODEL DESCRIPTION

1. Environment of the model

a. Database

(1) Ground Network. The Ground network has been expanded and consists of 35 physical nodes and 92 transit nodes. This is an expansion from the first generation FTLM of 16 physical and 25 transit nodes. [Ref. 14] The original EELS variant called for more nodes; however, due to hardware limitations and the computational complexity involved, this number was reduced. The physical nodes are all major cities. Both node types now have sensor reporting capability which provide reports for fusion in the C^3I process. The ground network interfaces with the sea network to facilitate amphibious assaults, unit landings, and pre-positioned afloat operations. The ground network also supports deep fires, described in a later section. There are three basic ground maneuver units: Infantry, Armor, and Mechanized. Each unit is equipped with personnel, equipment, MLRS (Blue only), and ADA. There are a total of 18 Blue divisions and 15 Red divisions.

(2) Air Network. The basic air network has not changed from the first generation FTLM. [Ref. 15] EETLM has been modified to include aircraft carrier based aircraft and cruise missiles (Tomahawk, harpoon, and TASM) in the network. However, the carrier aircraft and cruise missiles are not incorporated in the Air Module algorithms; they are currently scripted into the scenario. The strikes planned (aircraft, Tomahawk, and TASM) in support of the ground operation will either be executed in accordance with the planned schedule and configuration (if Red forces are in control of the targeted node) or canceled (if Blue forces are still in control of the targeted node). [Ref. 2]

(3) Naval Network. The Naval network contains 7 physical nodes and 12 transit nodes which are integrated into the overall network. The physical nodes are Carrier Operating Areas (CVOA). Both node types have sensor reporting capability. Naval ships currently have an impact on COA perceptions. Additionally, sensor reports on amphibious ships provide information for fusion in the C^3I process. An observation of an amphibious ship not only carries an observation as a ship, but also includes an observation of ground forces (men and equipment). This part of the observation is fused in the C^3I process and affects the perceptions of COAs. The ground and sea networks interface to facilitate amphibious assaults, unit landings, and pre-positioned afloat. There are nine basic Blue ship types: Aircraft carrier, Cruiser, Destroyer, Frigate, Landing Helicopter Assault (LHA), Landing Helicopter Dock (LHD), Landing Ship Dock (LSD), Landing Ship Tank (LST), and Maritime Preposition Ship. These basic ship types were chosen because they represent the backbone of today's and tomorrow's Navy. There are four basic Red ship types: Aircraft carrier, Cruiser, Destroyer, and Patrol Boat. The four basic Red ship types are not representative of the North Korean Navy; however, they are useful for testing the naval aspects of EETLM. Each ship is equipped with personnel, equipment, radar, and ADA. There are a total of 21 Blue ships and 7 Red ships in the current scenario. [Ref. 2]

b. Course of Action development

(1) Ground and Logistical units. Red has three viable courses of action (COAs). All COAs involve a logistical build-up of supplies, well forward, to support a massive offensive into South Korea. Prior to the massive offensive, Logistical Units will arrive. The Logistical Units are scheduled to arrive at their respective nodes at a rate which will insure all required logistical support is in position (in ground truth) by SIMTIME = 6.00. SIMTIME is the

simulation time and it is kept by the internal clock of the model. SIMTIME is initiated at the beginning of the simulation. A unit of time is currently defined as one day, but can be easily be redefined to reflect a more suitable time schedule. After the Logistical Units are in position (SIMTIME =6.00), the combat units will arrive at their respective nodes and commence hostilities. Red will attack using a specified Red COA at SIMTIME = 6.00. For example, the intermediate objectives for Red COA 1 are Seoul, Suwon, and the surrounding road network, with the final objectives being Kunsan, Taegu, Pusan, Kwangju, and Pohang. Each Red COA has a single corresponding Blue COA to counter it. The decision concerning which counter COA Blue will use, and when it will implement this COA, is based on Blue's perceptions of when Red will attack and which COA Red will use. Blue's perceptions are determined by sensor updates generated from observations of Red logistical units and combat units. The perception updating process, determined by logistical unit observations, is described in a later section. Blue may or may not have accurately perceived Red's intentions and may not be prepared (time-wise and/or COA-wise) to counter Red's offensive COA by attack time. The actual locations of all units, and details about each COA are given in Appendix A. The general concept of the operations for the Red COAs are based on the original FTLM Korean scenario developed by Karl Schmidt, but have been modified to suit the joint modeling requirements. [Ref. 14] A brief operational over view of all (Red and Blue) courses of action are provided below.

(a) COA 1

i. RED COA 1. This COA involves a 15 Division attack along the western and eastern corridors. At the commencement of hostilities, Haeju, Pyongyang, P'Yonggang, Wonsan, and Kosong will all have three divisions (each with 4 Brigades) attacking

from their respective locations. In Phase 1, Divisions 1, 4, 7, 10, 13 will attack from their respective nodes along the western and eastern corridors to seize the following objectives: Seoul, Kimhwa, Chunchon, Munsan (Chorwon), Kangnung (Kansong), respectively. In Phase 2, Divisions 2, 5, 8, 11, 14 (from their respective nodes and same corridors) will attack to seize the following objectives: Kongju, Wonju, Taejon, Suwon, Samchok, respectively. In Phase 3 Divisions 3, 6, 9, 12, 15 (from their respective nodes and same corridors) will attack to seize the following objectives: Kunsan, Kwangju, Pusan, Taegu, Pohang, respectively.

ii. BLUE COA 1. Blue conducts purely defensive operations. Prior to hostilities, Blue forces are positioned in depth to defend against a two pronged attack (western and eastern corridors) from the north.

(b) COA 2

i. RED COA 2. This COA involves an 11 Division attack along the western and central corridors. At the commencement of hostilities, Haeju will have 4 Divisions, Pyongyang (5 Divisions), P'Yonggang (4 Divisions), and Wonsan (2 Divisions). Each Division has a total of 4 Brigades. In Phase 1, Divisions 1, 10, 3, 6, 11 (from their respective nodes) will attack along the western and central corridors to seize the following objective: Seoul, Munsan, Kunsan, Wonju, Suwon, respectively. Divisions 4, 5, 12, 14 are held in reserve at Pyongyang. In Phase 2, Divisions 2, 7, 8, 13 (from their respective nodes and using the same corridors) attack to seize the following objectives: Taejon, Kwangju, Taegu, Chungju, respectively. In Phase 3, Divisions 9, 15 (from their respective nodes and using the same corridors) will attack to seize the following objectives: Pusan, Pohang, respectively.

ii. BLUE COA 2. Blue conducts purely defensive operations. Prior to hostilities, Blue forces are positioned in depth to defend against a two pronged attack (western and central corridors) from the north.

(c) COA 3

i. RED COA 3. This COA involves a 15 Division attack along three corridors: western, central, and eastern. At the commencement of hostilities, Haeju will have 3 Divisions, Pyongyang (7 Divisions), and Wonsan (5 Divisions). Each Division has a total of 4 Brigades. In Phase 1, Divisions 3, 4, 5, 10, 14 (from their respective nodes) will attack along the western, central, and eastern corridors to seize the following objectives: Seoul, Kimhwa, Chunchon, Munsan (Chorwon), Samchok, respectively. In Phase 2, Divisions 11,12 (from their respective nodes and using the same corridors) will attack to seize the following objectives: Suwon, Kongju, respectively. In Phase 3, Divisions 1, 2, 6, 7, 8, 9, 13, 15 (from their respective nodes and using the same corridors) will attack to seize the following objectives: Kunsan, Taejon, Wonju, Kwangju, Taegu, Pusan, Chungju, Pohang, respectively.

ii. BLUE COA 3. Blue conducts purely defensive operations. Prior to hostilities, Blue forces are positioned in depth to defend against a three pronged attack (western, central, and eastern corridors) from the north.

(2) Naval and Marine Units. The Naval COAs are held constant and support all the ground COAs in the same manner, within a specific run variant. Between run variants (cases), the naval COAs are changed. There are three variants: Case 1, early Naval involvement; Case 2, late Naval involvement; and Case 3, Joint (simultaneous) Army-Navy involvement. The Marine COAs are directly associated with the ground COAs. The Marines land and conduct their

appropriate ground COA. A limitation of EETLM is that the Naval operations are not dynamic. A temporary solution of scripting the naval operations has been adapted. [Ref. 2] The Marine ground COAs are described in Appendix A.

2. Command, Control, Communications, and Intelligence

a. Commitment of Joint Forces

At a strategic planning level (National Command Authority or Joint Chief of Staff), joint operations are the demonstrated ability to rapidly alert, mobilize, deploy, and operate military forces anywhere in the world. At present, the decision of when to commit such forces is held at the Presidential level. The key element in force projection operations is timely commitment of forces. The essential trade-off is between projecting the joint force rapidly, and projecting it with the right mix of combat power and resources to accomplish the mission. The more time a JTF Commander has prior to actual deployment, the better prepared and tailored the force will be to meet the mission. Joint forces are intended to deter, or to strike the decisive blow against an attacker, but are also prepared to conduct other missions. Typical missions include: establishment of a lodgment (air head or beach head line), seizure of an airfield or port facility, blocking, reinforcing, defending, or attacking. The EELS variant incorporates an algorithm which enables EETLM to independently decide when to commit joint forces. The algorithm is explained in greater detail in the Detection and Fusion section of this chapter. By varying the size of the forward deployed units and the early entry forces, the algorithm provides the capability to investigate the minimum size of forward deployed units. This will be left for future investigation. As stated in the thesis assumptions, any military operation of significant magnitude is generally predicated by a large amount of logistical build-up. The algorithm will focus on the logistical

build-up to obtain information on numbers and locations of units. With this information, COA probabilities can be determined and fused into the C^3I process to support the decision of where and when to commit forces.

b. Two sided perception

FTLM currently calculates perception of COAs for one side. The opposing side's COA is fixed, and the enemy does not use any perceptions to execute its COA. The model also calculates the probability associated with a Group's (Division's) composition (in terms of numbers and types of brigades) that feed the COA perceptions. FTLM does this by determining the possible permutations of all brigades available to the force. EETLM allows perceptions of COAs to occur on both sides. The perceptions are initially driven by sensor reports on logistical units once a deviation from the established status quo occurs. In order to arrive at a starting point for the simulation, Red's COA is predetermined. However, upon further refinement of the model, Red's COA need not be predetermined. Once the Red COA has commenced, the Blue force is free to choose any one of its three available COAs to counter the perceived Red COA.

c. Unit Movement

Specific changes to FTLM, to facilitate EETLM are:

(1) Army units move on maritime assets and are landed at seaports (ground - sea interface).

(2) Logistical units have been added to the model.

EETLM allows these logistical units to move within their assigned corridors to specified physical nodes (objectives). These units, as well as the combat maneuver units, use a minimum cost algorithm which considers the shortest distance, perceived enemy locations, and

tactical difficulty to move from node to node. [Ref. 14] All unit movement (Logistic units, Army combat units, and Marine units) is now detectable on both physical and transit nodes. Sensor observations contribute to the C^3I fusion process and COA perceptions. Naval and amphibious ships are also detectable and contribute to the C^3I fusion process and impact on COA perceptions.

d. Detection and Fusion

(1) Transit nodes and Physical nodes. In a major regional contingency (MRC), such as Korea, the total number of brigades size units could exceed 100 brigades. EETLM has the ability to detect on physical and transit nodes, and accommodate a total force structure of 130 brigades in the model. The fusion and detection process remains the same; however, EETLM requires a different method of calculating permutations than is currently being used by the first generation FTLM. EETLM uses the ground truth number of brigades associated with the Group/Division of interest as an upper bound, and then determines the possible permutations of the types of brigades available. The total number of permutations is more manageable than the number of permutations produced by FTLM, and provides the same level of information. From a military perspective, it is reasonable to have some information about the enemy in the area of operation (theater). A JTF Commander would have some prior intelligence about the size and composition of Divisions. For an example of how the permutation is actually calculated, refer to COA1.NET in [Ref. 14]. In COA1.NET, Group.1-1 consists of two Infantry Bdes, two Armor Bdes, and zero Mechanized Bdes, {2,2,0}. The ground truth number of brigades associated with Group1-1 is four. By obtaining all possible permutations of the three different types of brigades (Infantry, Armor, Mechanized); we find the total number of possible brigade permutations for Group1-1 is 24, ($P_{4,3}$). Again, from a military perspective, it is not unreasonable to expect a

Division to have three or four brigades, and to come from one of three major maneuver types (Infantry, Armor, or Mechanized). In this Korean scenario, the Group/Division size units will consist of a maximum of four brigades and will have only three brigade types (Infantry, Armor, and Mechanized). There are in excess of 60 brigade units on both sides in this scenario. The maximum number of brigade permutations for any Group/Division will be 24, ($P_{4,3}$). The large number of brigade units is required to demonstrate EETLM's ability to handle a more realistic theater size operation.

(2) Logistical Unit Information and COA Selection. The decision algorithm to commit forces, preceded by the algorithm assumptions, is outlined below. A flow chart is giving in Appendix B.

Algorithm Assumptions:

1. Sufficient logistical capability to support any of the Red COAs is NOT initially present in the area of interest.

2. The Logistical Stockpile Rates are the rates at which logistical units increase in specific areas of interest. These rates will increase over a short period of time, thus eliminating the possibility of rates remaining within established normal deviations (of logistic activities).

3. Logistical Stockpile Rate will increase constantly, once build-up commences. The constant rate results in a linear increase of total logistical units over time. If the rate was not constant, then other techniques, such as multiple linear regression, or least squares would have to be used to predict the increase of logistical units over time.

4. The perceived Time of Attack will be calculated, by Blue, every sensor update cycle. Once the difference between the perceived Time of Attack and Blue's response time is negligible

(less than 4 hours), the Perceived Time of Attack is held constant. This is referred to as decision time.

5. COAs perceptions will continually be updated. The Early Entry Force will deploy and conduct the COA associated with the enemy's COA having the highest probability at decision time.

6. Logistics units (logistics packages) are detectable in Brigade support size packages.

7. One logistics unit supports one generic brigade (either Armor, Mechanized, or Infantry).

8. Logistics units will move into the area of interest before combat units.

9. Two COA probabilities will be maintained. One set will be determined by logistics unit observations the other determined by combat unit observations.

Basic Algorithm:

1. Establish Status Quo. Identify the distribution (mean and variance) of the combat units (Brigade size), logistical units (sufficient logistics to support a Brigade in combat for one week), and logistics rates of the nodes within the areas of interest. The nodes in the respective areas of interest are determined by the analyst (they may fall within a certain distance or radius, or they may be important for other reasons, which are situation dependent).

2. Allocate sensors in four specific intelligence requirements areas.

(i) Logistics stockpiles

(a) Class I and V support for one Brigade in combat for one week.

(b) Side & Panel trailers, flat-beds, and low-boys.

(c) Fuel carriers and water trailers.

(ii) Construction assets, (i.e., warehouses, bridges, roads, and defensive positions).

(iii) Increased air activity.

(iv) Unit/Troop Movement.

3. Detect deviations from established status quo (e.g., an increase of one standard deviation from normal logistics activity). The size and number of deviations required to activate action 4, below, is an input parameter, and will be checked when conducting sensitivity analysis. However, once a deviation outside the prescribed parameters is noted, the algorithm will proceed with the following steps.

4. Reset all COA probabilities to equally likely and increase sensor reporting. This is necessary to reduce response time of the Bayesian update process. Thus, the most recent sensor observations will have more significant and timely impact on COAs updates, without having to overcome the bias of the initial perceptions (Figure 1).

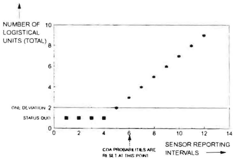


Figure 1. Increase In Logistical Units

5. Calculate the Logistical Stockpile Rates (overall and individual node) and Time of Attack. The Logistical Stockpile Rates are calculated in a two step process. First, the overall Logistical Stockpile Rate for the entire area of interest and Time of Attack must be determined. To calculate the Logistical Stockpile Rate, over some time period, the total increase in number of

logistical units is found. Dividing this overall total increase by the time period produces an overall Logistical Stockpile Rate. This calculated overall Logistical Stockpile Rate is used to determine a time until sufficient logistics units will be available to support the perceived minimum forces required to conduct any one Red COA. This time will be the perceived time until attack (Time of Attack). In the second step, the individual Logistical Stockpile Rates for each node within the area of interest are determined. The method for calculating these rates is similar to the overall total increase, except that instead of using the total logistical unit increase for the entire area, the logistical unit increase at a particular node is used, and is divided by the delta time period. This produces the individual node Logistical Stockpile Rates for each node in the area of interest.

6. Update COA probabilities using logistics unit observations. Multiplying the individual logistical Stockpile Rates for each node by the time until attack produces the number of Brigades that each individual node will be capable of supporting at the Time of Attack. The number of Brigades associated with each node can then be used to determine/update probabilities for each COA. The COA probability used will be the greater of the probabilities determined by logistics unit observations and by combat unit observations.

7. The Decision. The difference between the perceived Time of Attack and the response time required to provide sufficient forces in theater (Required Response Time) provides an interval of decision time. The decision to commit joint forces is made once the difference is zero. The required response time can also be adjusted to reflect political considerations (both domestic and international). Sensitivity analysis will be conducted to determine the potential impact of this adjustment of the critical time on the outcome of the early entry operations. A flow chart and example of this process are given in Appendices B and C.

(3) Indirect fire missions. Deep indirect fire assets have the capability to influence the battle before the close-in fight starts. A greedy artillery fire mission algorithm has been developed and implemented to allow deep fires. The closest unit to the enemy that does not have any firing constraints fires the deep mission. Deep fires are restricted by reloading times, number of volleys, and logistics.

Basic Algorithm:

1. Does unit have Multiple Launch Rocket System (MLRS)?

2. Is there an enemy unit on a physical or transit node which is in range? If so, the following elements must be addressed:

a. A sensor must be allocated and be providing continuous observations on the enemy unit.

b. Sensor must be capable of assessing battle damage.

c. Range calculation: Once an enemy unit intersects the range arc of a MLRS firing unit, the enemy becomes susceptible to MLRS fire. To calculate this

3. IF the above conditions are true:

THEN A Unit fires MLRS at the targeted enemy unit.

a. A unit fires a total of ten MLRS volleys (1 volley = 12 MLRS rounds). Then it must wait a prescribed time period before it can fire MLRS again.

b. Only one Blue Unit fires on an enemy in one time period. An Enemy unit cannot be re-engaged until one time period later.

c. Once the time period is over, re-engagement is allowed.

d. If there are two, or more units in range of an enemy unit, the closer unit fires its

MLRS first, then waits its required two periods The other units, if still in range, may fire after one time period has elapsed.

e. If there are two, or more enemy units within range, the closest enemy unit is fired on first, then the next closest enemy unit is engaged.

4. Units are not allowed to use up more than 50% of the allocated MLRS ammunition, unless the enemy unit is in an adjacent node. In this case, it may use up all MLRS ammunition, providing there are sufficient time periods available.

5. Amount of Attrition: Once a unit comes into range, the percentage of the unit susceptible to the lethal effects of the round will depend on number of rounds fired. A random number draw against a specific interval will specify this percentage. The intervals will correspond to the number of the round being fired (for 1st rounds (or volleys) fired: the interval is (30%-50%), for 2nd rounds fired: the interval is (40%-70%), for 3rd rounds fired or greater: the interval is (60%-85%). The percentage increases as the number of rounds fired increases, but only to a maximum of 85% of the unit being susceptible to indirect fire attrition. Adjudication is determined prior to any close combat attrition, so that deep fire effects can be realized. A flow chart of this process is given in Appendix D.

(4) Sensor Allocation. Physical nodes will be prioritized and packaged into sensor groups. For Red, the sensor packages will correspond to the attack phases, and incorporate all nodes in each phase. Since there are three phases in Red's planned operations, there will also be three sensor packages, each associated with their respective phase (see the ground COA section in Chapter II for the specific nodes per phase). Each sensor package will have a specified sensor observation frequency associated with it (High: one sensor observation every 6 hours, or Low:

one sensor observation every 12 hours). Generally, all sensor groups are in low sensor observation frequencies. As the Red forces progress through their operational phases (sensor groups), the sensor observation frequencies corresponding to the next phase (sensor group) is switched from low to high, and the old group is switched from high to low. Allocating sensors observations in this manner will allow Red to update its perceptions of Blue as the battle progresses, without adding too much computational burden to the model. These perception updates will allow for Red's COA updates, movement route selection, and aircraft targeting priorities to be based on their most recent sensor reports. Since the majority of the Blue forces are already in country (stationary on a physical node), detection on transit nodes only occurs when the reinforcing forces arrive. Once those forces are in their respective defensive position (physical nodes), there will no will longer be any detection on transit nodes for Red. Red's only source of intelligence will have to come from observations taken at physical nodes. The basic algorithm is as follows:

1. Establish sensor groups (a node can be included in more than one sensor group)

2. For each sensor group, assign frequencies for sensor observations to update perceptions (model input).

3. Initialize all sensor group frequencies.

4. Sensor observations are conducted in accordance with the prescribed frequency of the sensor group.

5. Sensor observation frequency of the next sensor group are changed from low to high, once 70% of the nodes in the current sensor group are occupied. The current sensor group sensor observation frequency is also changed, but from high to low.

6. If a Red unit attacks a node not in the current sensor group and the current sensor group is still not 70 % occupied, both sensor group's frequency will be high. Once the current sensor group finally reaches 70% its frequency will be reduced to low.

A flow chart of this process is given in Appendix E.

III. METHODOLOGY

A. ISSUES FOR INVESTIGATION

1. Impact of Joint Operations on COA Perceptions

Joint operations are the integrated military activities of two or more service components Army, Navy, Air Force, Marine Corps of the US military .[Ref. 1, pg. 4-1] The key to successful joint operations is synchronized employment of ground, air, naval, special operation forces, and space forces .[Ref. 1, pg. 3-1] To investigate the impact of the joint operations across each scenario entry case, the focus for analysis of this issue will be on the following areas:

a. Perception Changes Over time

How do the COA perceptions change over time? Does EETLM capture the COA perception changes when joint operations are being conducted? Examining this issue would provide insight into joint operations.

b. COAs chosen

Does EETLM choose the correct COA, for both Blue and Red? For planning purposes, knowing when and if an enemy is able to determine the correct COA is crucial.

2. Impact of time

a. When must the decision to commit joint forces be made?

The decision of when to comment joint forces is critical. As stated before, the key element in early entry operations is <u>timely</u> power projection. However, the essential military trade-off is between projecting the joint force rapidly and projecting it with the right mix of combat power and resources to accomplish the mission. To investigate this question, joint forces

are committed in a reinforcing role, with the mix (force size) and the forward deployed force size held constant. The relationship between when joint forces are committed (the reinforcement/delay time) and the size of the forward deployed forces is directly proportional. As the size of the forward deployed forces decreases, the reinforcement/delay time must decrease. Varying the entry time of joint forces will allow investigation of the impact of the speed and timing on the commitment of joint forces.

b. Preposition afloat

The capability of having equipment pre-positioned afloat is modeled by incorporating the times required to deploy Prepo Afloat units. The impact on the outcomes will provide insights on the deployment timing, and allow for study of the impact on COA perception.

3. Usefulness of EETLM to the JTF Commander

a. In the planning phase of the operation

During the planning phase of an operation, time is critical. All intelligence and insights available to the JTF Commander are used to develop courses of actions and conduct intelligence preparation of the battlefield (IPB). EETLM can provide the staff and JTF Commander with an idea of the potential outcomes of the COAs being considered. Weaknesses, or flaws in COAs can be exposed, critical events or times can be identified, and "what if" type questions can be explored. EETLM's scenario can be modified as different COAs are developed, new forces become available, or objectives change.

b. Enroute to the theater of operation

As intelligence and insights become available to the JTF Commander, EETLM's scenario can be modified to incorporate the new intelligence. The model results can be analyzed

to provide the JTF Commander with an idea of the potential impacts on specific COAs. This capability can be used while enroute to the theater of operation, permitting continuous planning prior to the operation.

c. Strength levels

(1) What were the strength levels (combat effectiveness levels) of all units? Were they above a minimum threshold? If a unit held, delayed, or achieved its objective, analysis of the combat effectiveness level will give an indication of the cost associated with doing so.

(2) What was the time associated with the above levels?

4. Minimum required number of forward deployed troop units

As noted earlier, this issue will be left for future investigation as described in Chapter IV. For the purposes of this thesis, the forward deployed force size will remain fixed.

B. MEASURES OF EFFECTIVENESS

To address the issues posed in the above section, the following methodology, measures of effectiveness (MOE), and data requirements will be used. The methodology for analysis of EETLM will focus on two main areas: perceptions of COAs over time and unit strengths. These two analysis areas were chosen to demonstrate EETLM's unique capability of using perceptions in its decision making, and to show the variability of outcomes. The second area was chosen to demonstrate EETLM's ability to provide standard output for traditional force ratio analysis, and to again show the variability associated with the outcomes. For the purposes of this thesis, large numbers of replications will not be run in order to produce a distribution of outcomes for analysis. A large number of replications would allow for the application of the central limit theorem and subsequent calculations of mean values and variances of outcomes. It would also allow for the

performance of t-tests and other appropriate statistical tests to determine if any statistical significant differences exists among the outcomes. This thesis will use the outcomes of three replications to demonstrate that the model produces variability in its outcomes. A data source matrix, outlining which data requirements will be used to answer specific MOEs, will be explained in detail in the following paragraphs.

1. Traditional Combat Analysis

The traditional MOEs, listed below, will be used. to address the following issues: the impact of time (Issues 2 a and b) and the usefulness of EETLM to a JTF Commander (Issues 3 a, b, and c).

a. $\left(\frac{\text{EndingStrength SIDE i}}{\text{Starting Strength SIDE i}}\right)$ ***% Remaining Force Ratio for both sides***

b. $\left(\frac{\text{Ending Blue Strength}}{\text{Ending Red Strength}}\right)$ ***Loss Exchange Ratio***

c. $\left(\frac{\text{Ending Air Assets Side i}}{\text{Starting Air Assets Side i}}\right)$ ***% Air Forces Remaining for both sides***

d. $\left(\frac{\text{Ending Naval Assets Side i}}{\text{Starting Naval Assets Side i}}\right)$ ***% Naval forces Remaining for both sides***

e. ***What caused the Theater Campaign to be stopped?***

(1) Did Red reach its objectives (all or some)?

(2) Did a side reach its breakpoint?

Three replications of the base case (Case 2, late Naval involvement) will be conducted to obtain a baseline. Recall the three Blue Cases: Case 1, early Naval involvement; Case 2, late Naval involvement; and Case 3, Joint (simultaneous) Army - Navy - Air Force and Marine involvement. .

The data requirements for the respective traditional MOEs analysis are as follows: These data requirements will be collected in all three replications.

DR 1. Starting and Ending Strengths of Ground units for both sides.

DR 2. Starting and Ending number of Air Force assets for both sides.

DR 3. Starting and Ending number of Naval forces for both sides.

DR 4. Listing of all unit locations (by node at end game).

DR 5. Listing of the combat and logistical strengths of all units (at end game).

2. Perception Analysis

The perception MOEs listed below will be used to address the following issues: the adequacy of EETLM to model a Joint Operation (Issues 1a and b); the impact of time (Issues 2 a and b); and the usefulness of EETLM to a JTF Commander (Issues 3 a and b).

a. Blue's perception of the three Red COAs, given a Red COA

b. Red's perception of the three Blue COAs, given a Blue COA

c. Blue's perception of the logistic unit rate increase

d. Blue's perception of Red's attack time

To obtain data for the above MOEs, 27 replications will be conducted. (Three replications per Side j's COA 1, 2, and 3, and per Blue Entry Case (1,2,3), over every sensor update cycle.) The data will be graphed over time to display changes in perceived COAs, the variability between replications, and the impact of joint operations (Case 3).

The data requirements for the perception analysis are as follows:.

DR 6. Side i's perception of all three of Side j's COA, given Side j is conducting COA X.

DR 7. Red's logistic unit rate as perceived by Blue .

DR 8. Red's attack time as perceived by Blue.

DR 9. Blue decision (time) for when to commit forces.

3. Data Source Matrices

The data requirements outlined in the two tables below will be collected during each replication to insure that all MOEs and issues are addressed. The first matrix (Table 1) associates MOEs with the Data Requirements and the second matrix (Table 2) associates MOEs with the Issues.

		MOE									
		1a	1b	1c	1d	1e i	1e ii	2a	2b	2c	2d
	DR 1	X	X								
	DR 2			X							
D	DR 3				X						
A	DR 4					X					
T	DR 5						X				
A	DR 6							X	X		
	DR 7									X	
	DR 8									X	X
	DR 9									X	X

TABLE 1. DATA REQUIREMENT VS MOE

		ISSUES						
		1	1	2	2	3	3	3
		a	b	a	b	a	b	c
MOE	1a					X	X	X
	1b					X	X	X
	1c					X	X	X
	1d					X	X	X
	1e i					X	X	
	1e ii					X	X	
	2a	X	X					
	2b	X	X					
	2c			X	X	X	X	
	2d			X	X	X	X	

TABLE 2. MOE VS ISSUE

C. CONDUCT OF THE SIMULATION

1. Purpose

The purpose of the simulation is to obtain all the data requirements needed for the MOEs and issues in accordance with the data source matrix. A total of 27 replications of EETLM were run: three replications of the three Red COAs for each of the three Blue cases (early Naval and Marine involvement, late Naval and Marine involvement, joint (simultaneous) Army, Navy, Air Force, and Marine involvement). Because the prototype model is not fully mature at this time (for reasons described later), complete statistical analysis using confidence intervals derived from a large number of replications is not appropriate for this thesis. Rather, three replications were run to show the stochastic behavior of EETLM. More replications can be run, as discussed in the Chapter VI, to investigate statistically significant differences produced by

smaller forward deployed force sizes and varied reinforcement/delay times. These investigations will be left for future research.

2. Simulation Events

The following events have been identified as being critical. Snapshots of the simulation will be taken at these times to obtain all the requisite data requirements.

a. STARTEX

STARTEX is the start of the simulation. At STARTEX (SIMTIME = 0.0), the status quo will be automatically initialized and Red logistical build-up will commence at a rate which will insure all Red logistical units are in position at SIMTIME = 6.00. All initial strengths will be reported at this time.

b. ATTACK TIME

Attack Time will occur at SIMTIME = 6.0. Red will commence the attack once all logistical units are in position (60 logistical units and SIMTIME = 6.0). This is also the beginning of Phase 1 of the operation. All Red combat units will start from one of four locations: Haeju, Pyongyang, P'Yonggang, Wonsan, and/or Kosong. The actual violation of the Demilitarized Zone (DMZ) will depend on travel time from the respective locations. All unit positions and COA perceptions will be reported.

c. PERCEIVED ATTACK TIME

Perceived Attack Time is the time Blue has estimated Red will attack. This time calculation is based on sensor reports of logistical units and combat units. These reports are fused into the C^3I process and a COA is also determined as the most likely Red COA at perceived attack time. Once the difference between the perceived attack time and the required response

time is zero, the perceived attack time is fixed and will not be subsequently updated. The decision to commit forces will be made and forces will start ingress. The COA chosen by Blue will be reported.

d. COA UPDATE CYCLE

The COA update cycle is an analyst input. Currently, the COA update cycle is set to once every 6 hours. At every update cycle the following information is reported:

- Perceptions of COAs
- Attack times
- Float time
- Logistic rates
- Logistic units totals (for both sides when applicable)
- Specified ground strengths.

e. SURFACE-TO-SURFACE ENGAGEMENTS

For every engagement, EETLM provides the following information:

- Side
- Mission
- Start of mission
- Time on target
- Target, Component
- Weapon
- Rounds fired
- Strength (before and after engagement).

f. ENDEX

ENDEX is the termination of the simulation. ENDEX occurs when one of two events occurs:

(1) Either side's ground-to-ground attrition strength falls below 50%, or

(2) Red has reached its final objective, Pusan. The final strengths of both sides and the positions of all units are reported at ENDEX. The ENDEX conditions were set by the author and may be changed.

3. Simulation Limitations

a. Attrition

The attrition model in EETLM is not fully developed. The attrition model currently in use is considered to be sufficient for this stage of development. In addition to an immature attrition model, the database consists of entirely notional data. All weapon capabilities and effectiveness have been selected to avoid document classification problems. Cause and effect relationships can be determined, but specific outcomes may be entirely the result of data selection.

b. Limited Replications

As indicated earlier, three replications of each of the three Red COAs over all three cases were run. The number of runs for this thesis are not sufficient to statistically validate any conclusions. The intent is to demonstrate EETLM's capability to provide analytical results. Once EETLM is fully developed, the model will be more suitable for providing multiple replications and a distribution of outputs.

c. Logistical Buildup

The logistical buildup occurs over a short interval and at a constant rate (6 days and at a rate of 2 log units per day per node). Because the time period is short and the rate is constant, there may not be significant variability of attack times, float time, and logistics rates between replications.

d. Scenario Specific

Since only limited replications are performed, caution must be used to insure the results obtained are not just "scenario specific". The results could be extreme values which are not indicative of average behavior. Obviously, a large number of replications should be made with the mature model for an actual study.

IV. RESULTS AND ANALYSIS

The reader is reminded that the results and their subsequent analysis were generated by EETLM using a fictitious database. The fictitious nature extended to every aspect within the database, of particular note: number of units; size of units; capabilities; strengths; equipment types; attrition; and logistic usage and re-supply rates, This was done intentionally to avoid classification problems. The consequences are that the results found may not be what one might intuitively expect. Additionally, EETLM is still a prototype model and has not reached full maturity, therefore not all algorithms are fully developed. Some algorithms are merely place holders, until more accurate algorithms can be developed and/or implemented and more computational power becomes available.

A. RESULTS

The results are presented in two sections. The results for the traditional combat analysis are presented first, followed by the results for the perception analysis.

1. Result for Traditional Combat Analysis

The data requirements for each of the traditional strength and ratio MOEs, as outlined in Chapter III, were collected and recorded in Tables G-1 through G-3, in Appendix G, with one table for each Red COA. The results displayed below in Table 3. R1-E1 Results, show Blue's strength levels (for Red COA 1, Blue entry case 1, replications 1, 2, and 3) and are part of Table G-1, located in Appendix G. These results will be discussed in detail. The reader is referred to Appendix G for the remaining results.

In case R1-E1, Red conducted Red COA 1 and Blue conducted entry case 1. In all replications, Blue chose its Blue COA 1 as its response COA.

GROUND TRUTH RED COA 1	BLUE	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH
CASE 1	REP 1	1	64946	202042	15744	24700	60989	188500
	REP 2	1	52523	202042	15042	24700	49219	188500
	REP 3	1	52523	202042	15041	24700	49220	188500

Table 3. R1-E1 Results

Blue's ending ground strength was 64946 in replication 1 and 52523 in replications 2 and 3. Blue started each replication with the same amount of ground strength, 202042. Blue's ending Logistical strength for replications 1, 2, and 3, respectively, were: 15744, 15042, and 15041. Blue started with 24700 logistical strength in all cases. Blue's starting personnel strength was the same for each case, 188500. Blue's ending personnel strength for replications 1, 2, and 3, respectively, were: 60989, 49219, and 49220. Appendix G (Figures G-4 through G-12) also contain maps of the final end state (ENDEX) of the simulation with all unit positions indicated by replication , Red COA (1, 2, or 3), and Blue entry cases (1 ,2 or 3), respectively. In R1-E1, Red penetrated to Kunsan, Taejon, Taegu, and Pohang. In replication 1, Red did have one unit penetrate to Pusan.

2. Results for Perception Analysis

The data requirements for each of the COA perception MOEs, as outlined in Chapter III, were collected and displayed in the graphs given in Appendix H (Tables H-1 through H-18). The data collected were graphed and displayed in sets by ground truth Red COA and Blue entry case. The results displayed below in Figure 2. R1-E1 Perception Results, show Blue's perception of Red COA 1 and Red's perception of Blue COA 1 (for Blue entry case 1, replications 1, 2,

and 3). In Figure 2, simulation time in days is plotted on the X-axis and Blue's perception (probability) of Red COA 1, given Red is actually conducting Red COA 1, is plotted on the Y-axis (the appropriate side is plotted on the Y axis for Red's perception of Blue). These results will be discussed in detail. The reader is referred to Appendix H for the remaining results.

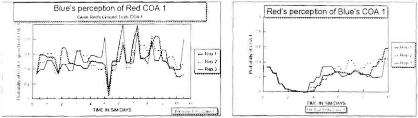


Figure 2. R1-E1 Perception Results

In case R1-E1, all COA probabilities start out at equally likely, P = 0.3333. Blue's perception of Red COA 1 stayed consistently high across replications and throughout the simulation, except for one dip at SIMTIME = 5.25. Red's perception of Blue COA 1 also started at equally likely, but dropped to near zero, across all replications, from SIMTIME = 2.0 to 4.0. After that point, Red's perception steadily increased.

The results displayed below in Figure 3. R1-E1 Perception Results, show Blue's perception of all Red COAs (for Blue entry case 1 by replication, only) and Red's perception of all Blue COAs. In Figure 3, simulation time in days is plotted on the X-axis and Blue's perception (probability) of all Red COAs are plotted on the Y-axis (the appropriate side is plotted on the Y axis for Red's perception of Blue). These results will be discussed in detail. The reader is referred to Appendix H for the remaining results

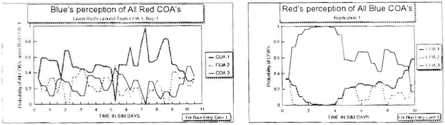


Figure 3. R1-E1 Perception Results

In case R1-E1, all COA probabilities start out at equally likely, P = 0.3333. Blue's perception of Red COA 1 stayed consistently high throughout the simulation, except for one dip at SIMTIME = 5.25. Blue's perception of Red COA's 2 and 3 were generally the smaller of the three. Red's perception of Blue COA 1 also started at equally likely, but dropped to near zero from SIMTIME = 2.0 to 4.0 then steadily increased until it became the dominant COA at the end of the simulation. Red's perception of Blue COA 3 was dominant until approximately SIMTIME = 9.0, at that point Red's perception switched to Blue COA 1. Red perception of Blue COA 2 remained the lowest throughout the entire simulation.

The data requirements for each of the logistic perception MOEs, as outlined in Chapter III, were collected and displayed in the graphs given in Appendix I (Tables I-1 through I-9). The data collected were grouped and displayed in sets by ground truth Red COA and Blue entry case. There was very little, if any, variation of logistical perception between Red COA, Blue entry case, and replication. The only differences were found in cases R1-E1 (perception of attack time, only) and R3-E3 (all Logistical MOEs). Blue's perception of Red's attack time asymptotically approached the true Red attack time of SIMTIME = 6.0. Recall that attack time is determined when Red has sufficient logistical units to support an offensive attack. Blue's perception of its

float time went to zero at approximately SIMTIME = 3.75. Blue's perception of Red's logistical flow was slightly lower than Red's, as was Blue's perception of Red's logistics rate. However, Blue's perceive logistics rate asymptotically approached Red's actual rate.

B. ANALYSIS

This analysis follows the same organization as described above. The analysis is addressed in two sections. The analysis of the traditional combat MOE's is presented first, followed by the analysis of the perception MOE's. The analyses of the traditional combat MOEs will be addressed by Red COA across all Blue entry cases. The COA perception analyses will be addressed by Blue entry case across all Red COAs. All numeric analyses are included in the appropriate appendices.

1. Analysis of Traditional Combat MOE's

The traditional analysis considers five MOEs, as described in Chapter III. Each MOE is addressed individually. Within each MOE, three strengths - Ground-to-Ground attrition; Logistical; and Personnel - is included in the analysis. In general, the ground-to-ground attrition strength and personnel strengths produced counterintuitive results for reasons discussed in the next section, whereas the logistics strength comparisons were reasonable. These results are presented in detail to give the reader an appreciation of the MOE analyses possible from EETLM. The results are given in Appendix J, Tables J-1 through J-8. Future refinements of the model and data will produce more accurate results for these MOEs.

a. $\left(\frac{\text{EndingStrength Blue}}{\text{Starting Strength Blue}}\right)$ *% Blue Force Remaining Ratio MOE*

(1) Ground-to-Ground Attrition Strength. Figure 4 graphically depicts the averages of the Ending Blue Ground-to-Ground Attrition Strength divided by the Starting Blue Ground-to-Ground Attrition Strength for Red COA 1 across each of the three entry cases. The

average ground-to-ground attrition strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining ground-to-ground attrition capabilities of Blue.

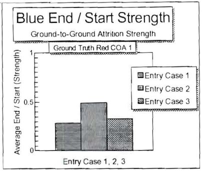


Figure 4. Ending Blue / Starting Blue Ground-To-Ground Attrition Strength

For all three Blue entry cases, Figure 4 shows that the average sizes of Blue forces at the end of the simulations were below 50%. The specific values for each entry case are given in Appendix J, Table J-1. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining Blue Ground-to-Ground attrition strength sizes. There was not a significant difference between entry cases 1 vs 3. In Blue entry case 2, the remaining Blue force size was the largest. In this case, the smaller Blue force (only the forward deployed force) was able to stop the larger red force without allowing any significant penetration into South Korea. In the other two Blue entry cases, Blue had a much larger initial force (forward deployed forces plus the joint reinforcing forces), when Red attacked, but Blue was not able to stop Red's penetration (this issue will be addressed in further detail in the Final Objective MOE). This result was counterintuitive. Because the smaller Blue force was able to stop the larger Red force, the late

arriving Blue joint reinforcing forces were not in the battle as long and, therefore, did not receive as many casualties. This would have allowed Blue entry case 2 to have a larger ending strength. However, the smaller initial force size and the late arrival of joint forces would have given the Red forces a larger ground-to-ground attrition advantage over Blue for at least the first two days of the conflict and allowed Red to attack the Blue forces in piecemeal and without the benefit of Naval Fire Support (Air and TLAMs), Marine amphibious assault forces, and Army follow-on Prepo afloat forces. This should have allowed for greater penetration into South Korea and more casualties on the initial Blue force and subsequently on the joint reinforcing forces, as compared to the other two Blue entry cases.

This result may have been caused by the rudimentary attrition model currently being used in EETLM and the fictitious database. The database does not accurately reflect attrition strengths for both sides, and this inaccuracy may have allowed Red to have more attrition effect on the joint forces than it realistically should have. If a better attrition model were employed, more reasonable attrition results would have been produced. Once the ATCAL - COSAGE attrition model and a more suitable database are incorporated in EETLM, the results should reflect the benefits of joint operations. These results may also be due to an inaccuracy within the computer code and/or a combination of all the above. This counterintuitive result was further investigated by graphing the average ground-to-ground attrition, personnel, and logistics strengths for the R1-E1 and R1-E2 cases. The results are given in Appendix J, Tables J-7 and J-8. In Appendix J, Table J-7, the R1-E1 graph, the personnel and ground-to-ground attrition strengths do not behave as expected. Both these strengths should not have had as steep an attrition slope as compared to the R1-E2 case. However, both have a steep slope, indicating Blue was attrited

by Red at a higher rate. This result means that the same size Red force was able to attrite a larger Blue force (R1-E1) faster than it did a smaller Blue force (R1-E2). Additionally, in both R1-E1 and R1-E2 cases, the ground-to-ground attrition, personnel, and logistical strengths started out at the same level. In the R1-E2 case, the initial force size should have been substantially less than that of the R1-E1 case and as a result all strengths should have been substantially smaller as well. In Appendix J, Table J-8, the average combat scores for R1-E1 and R1-E2 were graphed together for comparison. Table J-8 demonstrates the difference in slope between entry cases. In this particular graph R1-E2 ends before R1-E1, but in general, all other entry cases end at approximately the same time and produce the same results. These results seem to indicate there is a problem with the stopping rules of the simulation and with the attrition model. This will be addressed later in this chapter.

In Red COA 2, across all entry cases, the results were similar to the results of Red COA 1. Blue entry case 2 produced the most casualties, as compared to the other Blue entry cases. These results appears to be counterintuitive for the same reasons. The graphs are located in Appendix J, Table J-2.

In Red COA 3, the attrition was approximately equal across all entry cases. Here again, Blue entry case 2 should have produced more casualties, as compared to the other Blue entry cases, but did not. These results are also located in Appendix J, Table J-2.

(2) Logistic Strength. Figure 5 depicts the averages of the Ending Blue Logistic strength divided by the Starting Blue Logistic strength for Red COA 1 across each of the three entry cases. The average logistical strength is plotted on the Y axis and the three entry cases are

plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining logistical capabilities of Blue.

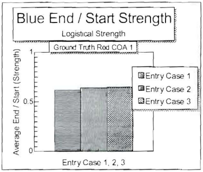


Figure 5. Ending Blue / Starting Blue Logistic Strength

For all three Blue entry cases, Figure 5 shows that the average magnitudes of Blue logistic strength at the end of the simulations were approximately equal and were slightly above 50%. The specific values for each entry case are given in Appendix J, Table J-3. In all entry cases, there was not a significant difference between the remaining Blue logistic strength. These results are intuitively correct, since a smaller force (the forward deployed forces) would have a larger logistics usage rate per unit compared to a larger force (the forward deployed forces and the joint forces). However the large force, since it inherently has more units, would have used more logistics. In the end, the overall logistic usage could be expected to be the same, or close, thus the remaining logistic levels could be expected to be the same.

In Red COA 2, across all entry cases, the average logistical strengths were approximately the same and were all above the 50% level. Blue entry case two, the late arrival of joint forces, had a slightly smaller logistical strength. These results are given in Appendix J, Table J-4.

In Red COA 3, across all entry cases, the results were similar to Red COA 2. All entry cases were above 50%, and were close in strength levels. Blue entry case two had the smallest logistical strength level of the three entry cases. These results are also given in Appendix J, Table J-4.

(3) Personnel Strength. Figure 6 depicts the averages of the Ending Blue Personnel strength divided by the Starting Blue Personnel strength for Red COA 1, across each of the three entry cases. The average personnel strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining personnel strengths of Blue.

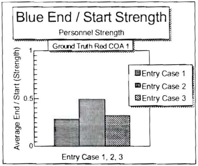


Figure 6. Ending Blue / Starting Blue Personnel Strength

For all three Blue entry cases, Figure 6 shows that the average sizes of Blue forces at the end of the simulations were below 50%. The specific values for each entry case are given in Appendix J, Table J-5. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining Blue Personnel strength sizes. There was not a significant difference between entry cases 1 vs 3. In Blue entry case 2, the remaining Blue personnel strength size was the largest. These results mirrored the results of the ground-to-ground attrition, as one would

intuitively expect. Combat attrition is highly dependent on the number of personnel, and these results indicate that the attrition process is affecting both parameters in the same manner. However, both results were counterintuitive, as explained in the ground-to-ground attrition case.

The results from Red COA's 2 and 3, across all Blue entry cases, also follow the ground-to ground attrition results and are given in Appendix J, Table J-6.

b. $\left(\frac{\text{EndingStrength Red}}{\text{Starting Strength Red}}\right)$ ***Red Force Remaining Ratio MOE***

(1) Ground-to-Ground Attrition Strength. Figure 7 graphically depicts the averages of the Ending Red Ground-to-Ground Attrition Strength divided by the Starting Red Ground-to-Ground Attrition Strength for Red COA 1, across each of the three entry cases. The average ground-to-ground attrition strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining ground-to-ground attrition capabilities of Red.

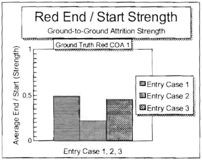


Figure 7. Ending Red / Starting Red Ground-To Ground Attrition Strength

For all three Blue entry cases, Figure 7 shows that the average sizes of Red forces at the end of the simulations were at, or below 50%. The specific values for each entry case are given in Appendix J, Table J-1. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining Red Ground-to-Ground attrition strength sizes. There was not a

significant difference between entry cases 1 vs 3. In Blue entry case 2, the remaining Red force size was the smallest. These results were consistent with Blue's ground-to-ground attrition strength results; however, they were counterintuitive for the same reasons. The second Blue entry case had the late arrival of the joint forces. The late arrival of joint forces should have produced a larger remaining force size then the other entry cases, because the defenders (the Blue forward deployed ground forces) were without the benefit of Naval Fire Support (Air and TLAMs), Marine amphibious assault forces, and Army follow-on Prepo afloat forces for at least two days. This would have given the Red forces a larger ground-to-ground attrition advantage over Blue for at least the first two days of the conflict, as compared to the other two Blue entry cases. As previously discussed, these results may have been caused by the rudimentary attrition model, the fictitious database, and or the unverified computer code, currently being used in EETLM . Once a better attrition model is incorporated, further investigation is warranted.

The results from Red COA's 2 and 3, across all Blue entry cases, also follow the Blue ground-to ground attrition results.

(2) Logistic Strength. Figure 8 depicts the averages of the Ending Red Logistic strength divided by the Starting Red Logistic strength for Red COA 1, across each of the three entry cases. The average logistical strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining logistical capabilities of Red.

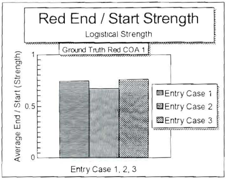


Figure 8. Ending Red / Starting Red Logistic Strength

For all three Blue entry cases, Figure 8 shows that the average sizes of Red logistic strength at the end of the simulations were above 65%. The specific values for each entry case are given in Appendix J, Table J-3. In entry cases 1 and 3, the remaining Red logistics strengths were the highest. In entry case 1 vs 3, there was not a significant difference between the remaining Red logistic strength sizes. There was a significant difference between entry cases 1 vs 2 and 2 vs 3. These results were consistent with the results of Red's ground-to-ground attrition strength results. In entry cases 1 and 3, Red had less attrition and, consequently, had not fought as hard, thereby using less logistics. However, these results were counterintuitive. In both entry cases 1 and 3, the Red forces faced a larger Blue force and should have intuitively had to fight harder, and used more logistics than in entry case two (late arrival of joint forces, and consequently, a smaller Blue force for at least the first two days). Since these results were consistent, it appears that the rudimentary logistics model currently being used in EETLM is producing reasonable results.

In Red COA 2, across all entry cases, the average logistical strengths were approximately the same and were all above the 75% level. Blue entry case two, the late arrival of

joint forces, had a slightly larger logistical strength. These results are given in Appendix J, Table J-2.

In Red COA 3, across all entry cases, the results were similar to Red COA 2. All entry cases were above 65%, and were close in strength levels. Blue entry case two had the smallest logistical strength level of the three entry cases. These results are also given in Appendix J, Table J-4.

(3) Personnel Strength. Figure 9 depicts the averages of the Ending Red Personnel strength divided by the Starting Red Personnel strength for Red COA 1, across each of the three entry cases. The average personnel strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining personnel strengths of Red.

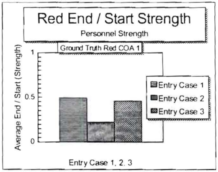


Figure 9. Ending Red / Starting Red Personnel Strength

For all three Blue entry cases, Figure 9 shows that the average sizes of Red forces at the end of the simulations were below 50%. The specific values for each entry case are given in Appendix J, Table J-5. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining Red Personnel strength sizes. There was not a significant difference

between entry cases 1 vs 3. In Blue entry case 2, the remaining Red personnel strength size was the smallest. These results were again consistent with Red's ground-to-ground attrition strength results; however, they were still counterintuitive. The explanation of these results is the same as the Red ground-to-ground attrition strength results. The results from Red COA's 2 and 3, across all Blue entry cases, were also consistent with their respective Red's ground-to ground attrition results, given in Appendix J, Table J-6.

c. $\left(\frac{\text{Ending Blue Strength}}{\text{Ending Red Strength}}\right)$ ***Loss Exchange Ratio MOE***

(1) Ground-to-Ground Attrition Strength. Figure 10 depicts the averages of the Ending Blue Ground-to-Ground Attrition Strength divided by the Ending Red Ground-to-Ground Attrition Strength for Red COA 1, across each of the three entry cases. The average ground-to-ground attrition strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining ground-to-ground attrition capabilities of Blue as compared to Red. Values greater than 1.0 indicate that Blue's Ending capabilities were more than Red.

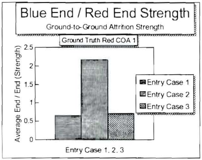


Figure 10. Ending Blue / Ending Red Ground-To Ground Attrition Strength

For Blue entry cases 1 and 3, Figure 10 shows that the average sizes of Blue forces at the end of the simulations were less than Red. In entry case 2, the average Blue force size at the end of the simulation was greater than Red. The specific values for each entry case are given in Appendix J, Table J-1. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining ground-to-ground attrition strength sizes. There was not a significant difference between entry cases 1 vs 3. These results were consistent with the results from the Blue and Red attrition strengths, but again were counterintuitive as discussed previously.

The results from Red COA's 2, across all Blue entry cases, were also consistent. In this case, Red's ending force sizes were larger than Blue's across all entry cases.

The results from Red COA's 3, across all Blue entry cases, were also consistent. In this case, Red's ending force sizes were smaller than Blue's across all entry cases. The results are given in Appendix J, Table J-2.

(2) Logistic Strength. Figure 11 depicts the averages of the Ending Blue Logistic strength divided by the Ending Red Logistic strength for Red COA 1, across each of the three entry cases. The average logistical strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining logistical capabilities of Blue as compared to Red. Values greater than 1.0 indicate that Blue's Ending capabilities were more than Red.

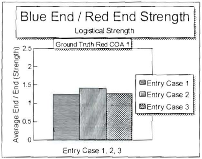


Figure 11. Ending Blue / Ending Red Logistic Strength

For all three Blue entry cases, Figure 11 shows that the average sizes of Blue logistic strength at the end of the simulations were greater than Red. Blue entry case 2 produced the largest remaining Blue logistic strength as compared to Red. The specific values for each entry case are given in Appendix J, Table J-3. In all entry cases, there was not a significant difference between the remaining Blue logistic strength sizes. These results were intuitively correct, since in both entry cases 1 and 3, the Red forces faced a larger Blue force and would have intuitively had to use more logistics, possibly resulting in a larger Blue ending logistical strength. In the end, the overall logistic usage could be expected to be the same or close, which is the case for all entry cases.

The results from Red COA's 2 and 3, across all Blue entry cases, were similar. All Blue's ending logistical strengths were greater than Red's. The difference between Red COA 1 and Red COA 1 and 3, was in Blue entry case 2. In Blue entry case 2, Blue's logistical strength levels were slightly smaller than in entry cases 1 and 3, but as previously mentioned were still larger than Red's. The results are given in Appendix J, Table J-4.

(3) Personnel Strength. Figure 12 depicts the averages of the Ending Blue Personnel strength divided by the Ending Red Personnel strength for Red COA 1, across each of the three entry cases. The average personnel attrition strength is plotted on the Y axis and the three entry cases are plotted on the X axis. This graph demonstrates the differences, between the joint entry cases, of the remaining personnel strengths of Blue as compared to Red. Values greater than 1.0 indicate that Blue's Ending strengths were more than Red.

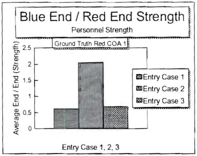


Figure 12. Ending Blue / Ending Red Personnel Strength

For Blue entry cases 1 and 3, Figure 12 shows that the average sizes of Blue personnel strength at the end of the simulations were smaller than Red. In Blue entry case 2, Blue's average personnel strength size at the end of the simulation was larger than Red. The specific values for each entry case are given in Appendix J, Table J-5. In entry cases 1 vs 2 and 2 vs 3, there was a significant difference between the remaining Blue personnel strength sizes. There was not a significant difference between entry cases 1 vs 3. In Blue entry case 2, the remaining Blue personnel strength size was the largest. These results were consistent with the results from the Blue and Red personnel strengths, but again were counterintuitive as discussed previously. The explanation of these results is the same as the ground-to-ground attrition and personnel strength results.

The results from Red COA's 2, across all Blue entry cases, were also consistent. In this case, Red's ending personnel sizes were larger than Blue's across all entry cases.

The results from Red COA's 3, across all Blue entry cases, were also consistent. In this case, Red's ending personnel sizes were smaller than Blue's across all entry cases. The results are given in Appendix J, Table J-6.

d. Air Force and Naval forces

The analysis of MOEs pertaining to all naval and Air Force aspects are presented in LT Michael Fulkerson's thesis [Ref 2].

e. Stopping Rules

(1) Final Objectives. The results for all Red COAs, across all Blue entry cases, are given in Appendix G, Figures G-1 through G-12. The results for Red COA 1 are given in Figures G4 through G6. In R1-E1 (Figure G-4), replication two, Red came close to reaching Pusan, but was stopped at Pohang, which is the next city to the east of Pusan. In replication three, Red did succeed in reaching Pusan. The thick outline represents the area under Red's control at ENDEX. The reader will note the dashed part of the thick outline, which is the only difference between replications 1 and (2 and 3). The results of all three replications for R1-E2 and R1-E3 are displayed in Appendix G, Figures G-5 and G-6, respectively, for comparison. In the R1-E2 case, Red's penetration into South Korea was not nearly as extensive as in R1-E1 or R1-E3. In R1-E2 replications, Red forces were stopped by Suwon and Yongdok (the reader is reminded that the objective for Red, across all its COAs, is to reach Pusan). Again, the thick outline indicates the area under the control of Red. R1-E3 is very similar to the first case, R1-E1. In both cases Red had substantial penetration into the south. The difference between these two cases is that Red did

not reach Pusan. Red was stopped at Pohang, the next city to the east of Pusan. These results are counterintuitive as well. In the R1-E1 and R1-E3 cases, Red penetrated the farthest into the south. In both these cases, Blue had a much larger initial joint force present. In the R1-E2 case, initial Blue forces (the forward deployed ground forces) were without the benefit of Naval Fire Support (Air and TLAMs), Marine amphibious assault forces and follow-on Army Prepo Afloat forces, for at least the first two days. This would have given the Red forces a larger advantage over Blue for at least the first two days of the conflict and allowed them to penetrate as far or farther than the other two Blue entry cases. In Red COA 1, across all three entry cases and all three replications, Red reached its final objective, Pusan, only one time. In general, the simulation was not terminated as a result of the final objectives being reached.

The results of Red COA 2 are given in Appendix G, Figures G-7 through G-9. The results, across all entry cases and all replications in the Red COA 2, were very similar. Red penetrated the furthest into South Korea in case R2-E2, where it reach Pusan in replication two, and was on the transit node leading into Pusan on the other replications one and three. In R2-E1 and R2-E3, Red penetrated as far as Taegu, the next city to the north of Pusan. In Red COA 2, across all three entry cases and all three replications, Red reached its final objective, Pusan, only one time. In general, the simulation was not terminated as a result of the final objectives being reached.

The results of Red COA 3 are given in Appendix G, Figures G-10 through G-12. Across all entry cases and all replications in the Red COA 3, the results were very similar. Red penetrated the furthest into South Korea in case R3-E2, where it reach Pohang (the next city to the east of Pusan), Chungju and Kongju in replications one and two. In R3-E1 and R3-E3, Red

penetrated as far as Yongdok (the next city to the east of Pohang), Chunchon, and Kongju. In Red COA 3, across all three entry cases and all three replications, Red failed to reach its final objective. The simulation was not terminated as a result of the final objectives being reached.

In general, for all Red COAs and Blue entry cases, the simulation was not terminated due to Red reaching its final objective.

(2) Break Points. The ground-to-ground combat attrition break point data are given in Appendix J, Table J-1. In all cases, except for the two cases noted above, the simulation terminated because one or both sides had reached their break points. In most cases one or both sides were well below the established break point of 50% before the simulation terminated, indicating another area for future investigation.

2. Analysis of the Perception MOE's

All COA perception results are given in Appendix H (Tables H-1 through H-18). The graphs in set 1 show that there was a general similarity between specific COAs, across replications, but that there was also variability between replications. There were no two COA perceptions that were the same. Given the model's design, the variability and the similarity were expected.

a. COA Perceptions

(1) Ground Truth Red COA 1. The graphs for Red COA 1 (Blue entry cases 1 through 3) are given in Appendix H, Tables H-1 through H-6. Even with the variability between replications, Blue's perception of Red's ground truth COA 1, in the R1-E1 through E3 entry cases, was generally above the 50% probable level. In all replications within this entry case, when

Blue made the decision to commit forces, Blue also correctly chose Red COA 1 as the most probable COA Red would pursue. Even though Blue perceived, and subsequently selected the correct Red COA in all replications and entry cases, the probability level associated with Blue's perception of Red's COA 1 intuitively should have been higher and more stable. Only in Red's ground truth COA 1 were logistic and combat units sent to Kosong. Once a logistics unit was detected enroute to, or in Kosong, the probability of Red COA 1 should have approached 1.0, since there were no other possible COAs that involved Kosong. There were two replications where Blue's perception of Red COA 1 did not finish as the dominant one, one replication in each of the following cases: R1-E1 and R1-E2. In both R1-E1 and R1-E2, Blue's perception of Red COA 1 was dominant throughout most of the simulation, however at the very end (the last half of a day, in SIMTIME) Blue's perception of Red COA 1 fell. This is a cause for further investigation to insure the proper functioning of the computer code within the model. Red's initial perception of Blue's COA, in all replications within this entry case, heavily favored Blue's COA 3. By attack time (SIMTIME = 6.0), Red's perception of Blue's COA 1 had started to increase (to approximately 0.35), but Red's perception of Blue's COA 3 was still favored. Red's perception of Blue COA 3 stayed dominant across all replications and entry cases until SIMTIME = 9.5, 7.0, and 7.75 (R1-E1, R1-E2, R1-E3, respectively). After the SIMTIMES previously mentioned, Red's perception of Blue's COA vacillated. Blue COA 1 did finish as the dominant the majority of the times (six out of the nine possible times), Blue COA 3 finished dominant twice and Blue COA 2 finished once as the dominant COA. This is also cause for further investigation to insure the proper functioning of the computer code within the model, specifically near the end of the simulation.

(2) Ground Truth Red COA 2. The graphs for Red COA 2 (Blue entry cases 1 through 3) are given in Appendix H, Tables H-7 through H-12. Blue correctly perceived and chose Red's ground truth COA in only one entry case, R2-E1. In R2-E1 (for all replications), Blue made its decision on Red COA at SIMTIME = 2.5. In all other cases, Blue did not decide until SIMTIME = 3.75. If Blue had made all decisions at SIMTIME = 2.5, Blue would have chosen Red COA 2, across the board. If Blue had made all decisions at SIMTIME = 3.75, it would have chosen Red COA 1, across the board. In all three entry cases, prior to attack time, Blue's perception of Red's COA was very erratic, not favoring any specific Red COA. In every case, after attack time, Blue's perception of Red ground truth COA 2 became the dominant one. Red perception of Blue's COA were similar in behavior to Red Ground Truth COA 1, discussed above. Red's perception of Blue's COA 3, prior to attack time, was consistently the dominant COA. Not until late (approximately: SIMTIME = 8.0) in the simulation did Red's perception of Blue's COA 1 start to increase. However, Red's perception of Blue COA 3 remained the dominant COA, throughout the simulation. Red may have incorrectly perceived Blue's COA, because the distinctions between the Blue COA's 1 and 3, are not as readily apparent. The differences are noticeable in the southern parts of the central and eastern corridors.

(3) Ground Truth Red COA 3. The graphs for Red COA 3 (Blue entry cases 1 through 3) are given in Appendix H, Tables H-13 through H-18. Blue's perceptions of Red's ground truth COA 3, at decision time, was incorrect across the board. The differences between Red COA 1 and 3 are not very apparent after the attack commences. However, prior to the attack, there were differences which Blue should have been able to detect. In Red COA 1, there were logistical and combat units at Kosong; however, in Red COA 3 there were not. Even

though both COAs attack down the eastern corridor, the presence or lack of presence of units in Kosong should have been sufficient to distinguish between the two COAs. This is a cause for further investigation to insure the proper functioning of the computer code within the model. As discussed in Red Ground Truth COA 2, Red's perception of Blue's COA 3, prior to attack time, was consistently the dominant COA. Red's perception of Blue COA 3 remained the dominant COA throughout the simulation.

(4) General Trends for all Red COAs. Regardless of entry case, or replication number, the Red COA perceptions were almost exactly the same until SIMTIME = 4.25. For example, in R1-E1, Red's perception of Blue's COA 1 was almost the same for all replications and also for R1-E2 and R1-E3. The same was true for Red's perception of Blue's COAs 2 and 3, as well as for R2-E1, R2-E2, R2-E3 and R3-E1, R3-E2, R3-E3. This result is also explainable. During Red's build-up phase, SIMTIME 0.0 to 6.0, Blue's forward deployed forces did not move, therefore nothing changed between replication, COA, or entry case until the joint forces arrived. The decision to commit the joint force was dependent on Blue's prediction of Red's attack time, but occurred before SIMTIME = 4.25. The ranges of decision times were from SIMTIME = 2.5 to SIMTIME = 3.75. By SIMTIME = 4.25, Red sensor's were detecting the arriving Blue units, and changes in perception were recorded. The variability in Blue's prediction of Red's attack time will be analyzed in the next section. The above events were probably due to the lack of any changes in the Red logistic units flow. Until SIMTIME = 6.0, the only sensor observations being generated were from sensor observations of Red logistical units. Since the flow of Red logistical units did not change between replications, it is reasonable that the perceptions generated from these observations would be very similar until SIMTIME = 6.0 (the logistical flow did change

between Red COAs). Recall that at SIMTIME = 6.0, Red conducted its attack and combat units were then detectable.

In case R1 (Red ground truth COA 1), and across all entry cases (Blue entry cases 1, 2, or 3), every first replication produced the same Blue perception of Red COA 1, 2, and 3 until approximately SIMTIME = 2.5. The reader will notice that the replication 1's of Blue's perception of Red COA 1, across all Blue entry cases (in ground truth Red COA 1) were the same until approximately SIMTIME = 2.5. After that time, only the replications from entry cases 2 and 3 remained the same. The replications from entry cases 2 and 3 were the same until approximately SIMTIME = 5.0, then all were different. For example, replication 1, from R1-E1, was the same as replication 1 from R1-E2 and replication 1 from R1-E3 until SIMTIME = 2.5, and then only the replications from R1-E2 and R1-E3 were the same. Note, however, that the replications were different within an entry case. This was also true for R2-E1, R2-E2, R2-E3, but not for R3-E1, R3-E2, R3-E3. This result is unexplainable at this time and is a cause for further investigation to insure the proper functioning of the computer code and the perception algorithm within the model.

b. Attack Time Perceptions

The results of all the attack time perceptions were generally the same for all combinations of Red COA and Blue entry case. These results are given in Appendix I, Tables I-1 through I-9. Within a Red COA and Blue entry case, there was some small variability between replications, but the variability was so minute the differences were graphically undetectable (the differences normally occurred in the third or fourth decimal place). The only noticeable difference was in replication 1 of R1-E1 and R3-E3. These two cases were different from the other cases,

but were almost identical to each other. These similarities are explainable. Prior to attack time, COA perception updates were only affected by logistic unit detections and subsequent sensor observations. No other detections and sensor observations contributed to the COA perception updates until after that time. Since the logistics flow rate was constant throughout the logistical build-up period (SIMTIME 0.0 - 6.0) and there was sufficient time for several sensor update cycles, the effect of the variability in the Blue sensors on the overall COA was minimal.

Figure 13 shows Blue's perception of Red's attack time for R3-E3. Simulation time in days is plotted on the X-axis and Blue's perception of Red's attack time is plotted on the Y-axis. The actual attack time (ground truth for Red) is plotted at SIMTIME = 6.0 days. Recall that attack time is determined when Red has sufficient logistical units to support an offensive attack. The horizontal line, labeled actual attack time, indicates this event. Blue's perceived attack time (as discussed previously in the logistics rate algorithm) is a time prediction of when Blue thinks Red will have sufficient logistics stockpiles forward to support an offensive attack. The other three curves reflect the change in Blue's perception of Red's attack time for the three replications. There was some variability between replications, most notably between replications (1 and 2) and 3. There was no difference between replications 1 and 2.

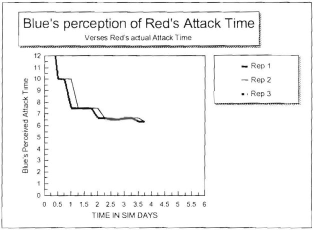


Figure 13. Attack Time

Blue's perception of the attack time asymptotically approached Red's true attack time, SIMTIME = 6.0. This perception and all the following perceptions were carried out only until Blue was forced to make a decision to commit forces. In general, Blue's decision was made between SIMTIME = 3.75 and 4.25. The model stopped the COA perceptions calculation based on logistical unit detections and subsequent sensor observations when the float time went to zero. This was due to the computation burden it placed on the current computer platform. Once the computational limitation is reduced, COA perceptions can be calculated by sensor observations from both logistical units and combat units. As mentioned, cases R1-E2 through E3, R2-E1 through E3, and R3- E1 through E2 are almost identical to replications 1 and 2 in R3-E3.

In Figure 14, Blue's perceived float time is displayed. Simulation time in days is plotted on the X-axis and Blue's perception of Red's attack time is plotted on the Y-axis. The actual attack time (ground truth for Red) is plotted at SIMTIME = 6.0 days. Recall that attack

time is determined when Red has sufficient logistical units to support an offensive attack. The horizontal line, labeled actual attack time, indicates this event. Blue's perceived attack time (as discussed previously in the logistics rate algorithm) is a time prediction of when Blue thinks Red will have sufficient logistics stockpiles forward to support an offensive attack. The other three curves reflect the change in Blue's perception of Red's attack time for the three replications. Again, there is very little variability between replications and cases.

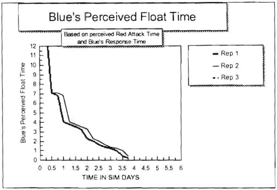


Figure 14. Float Time

In replications 1 and 2, Blue's float time went to zero at SIMTIME = 3.75, whereas in replication 3 the float time went to zero at SIMTIME = 4.0. The decision to commit forces was made later in this replication. As mentioned earlier, cases R1-E2 through E3, R2-E1 through E3, and R3- E1 through E2 are almost identical to replications 1 and 2 in R3-E3.

Figure 15 depicts the constant logistical build-up and Blue's perception of Red's logistical build-up. The reader will note that for all replications, the perceived logistical build-up is below Red's actual value. If the perceived build-up lines were extrapolated until they intersected the 60 logistical units level, the SIMTIME would be slightly larger than SIMTIME =

6.0. As a result, the arrival of Blue's reinforcing forces were slightly late. Cases R1-E2 through E3, R2-E1 through E3, and R3- E1 through E2 are almost identical to replications 1 and 2 in R3-E3.

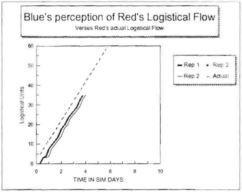


Figure 15. Logistical Flow

In Figure 16 the Blue's perceived total logistical rate (per day) is shown. Red's actual rate is 12.5 logistical units per day per node. The reader will note that Blue's perception of Red's logistical rate initially increased dramatically and then flattened out from SIMTIME = 1.0 to 2.0. Since Blue did not have continuous sensor observations of Red, the initial dramatic rise in the perceived rate was a reflection of the build-up that occurred between sensor update cycles. Recall that initially, the sensor update cycle is once every twenty four hours and is not increased until Blue has perceived an increase in the rate outside of the established status quo. Once the increase is determined to be outside the status quo, the sensor update cycle is increased to once every two hours. The flat area is indicative of no sensor observations during that period. After the sensor update cycle was increased (SIMTIME = 2.0), the increase in Blue's perceived logistical rate asymptotically approaches the actual rate. As previously mentioned, cases R1-E2

through E3, R2-E1 through E3, and R3- E1 through E2 are almost identical to replications 1 and 2 in R3-E3.

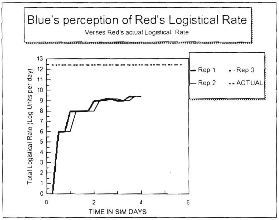


Figure 16. Logistical Rate (per day per node)

V. CONCLUSIONS AND RECOMMENDATIONS

Even though the analyses of the situation indicate current model shortcomings, they demonstrate that EETLM is capable of providing meaningful results and analysis of joint operations conducted in an uncertain world. Not only are the joint operational decisions made in a stochastic environment, as opposed to a deterministic one, but they are made under uncertainty, with the best incomplete information available, and not made based on ground truth. This approach allows for more realistic investigations of operations in the new world order. Again, the reader is reminded that the model is still in a prototype development stage, and this thesis has identified current areas of deficiency. However, once those identified problems are corrected and a more suitable computational platform is adopted, conclusions drawn from similar analyses will be much more beneficial.

A. CONCLUSIONS

The original problem statement was decomposed into three separate issues for investigation in Chapter III. Those issues were investigated in Chapter IV and the conclusions for those issues are listed below. From these conclusions the answer to the thesis' problem statement will be drawn.

1. Impact of COA Perceptions on Joint Operations

a. Perception Changes Over time

From the results given in Appendix H, the reader can conclude that there was a very limited impact of joint operations on Red's perception of Blue's actual COA. This was a result of the lack of more than one Naval COA. The Navy generically supported all the theater

COAs in the same manner, no matter which ground COA Blue was actually pursuing. Therefore, the impact the joint operations made on Red's COA perceptions was not significant between COAs and entry cases. Future applications should incorporated different Navy COAs, to include feigned amphibious assaults or troop landings, so that the impact on Red's perception of the actual COA Blue chosen is realized.

b. Perceptions of COAs

As discussed above, the joint forces provided little impact on Red's perception of Blue's COAs. Analysis of the COA graphs revealed that Red, on every occasion, initially perceived Blue's COA to be COA 3. This perception was dominant until after attack time. Therefore, if Red had the opportunity to actually choose the COA it wanted to pursue, Red would have chosen to pursue their COA which was most advantageous (recall that the user currently predetermines the COA which Red will pursue). Dynamic selection of COAs by both sides during model execution is a subject for future research. Blue's perception of Red's COA were fairly consistent and accurate for Red COAs 1 and 2, but inconsistent for Red COA 3.

2. Impact of time

a. When must the decision to commit Joint forces be made?

The impact of when to commit joint forces was demonstrated in the analysis of the force strengths. There were significant differences in strength levels (ground-to-ground, logistics, and personnel) between entry cases. Recall the entry cases: case 1; early arrival of joint forces; case 2; late arrival of joint forces; and case 3, on time arrival of joint forces. The late arrival of joint forces was introduced so that the effect of not having joint forces when hostilities commenced, for whatever reason, could be assessed. As discussed in Chapter IV, the analyses of

the MOEs indicates model enhancements are required to produce more meaningful results. Once the model has matured, this type of analyses should be revisited.

b. Preposition afloat

Prepo Afloat was modeled in EETLM. The reinforcing Army units, as part of the joint force, were carried on maritime preposition ships (MPS). The Prepo units arrived with the joint force, and went into combat. The off-loading, marshaling, and tactical assembly were not modeled in any detail in this thesis, but could easily be incorporated in future versions of EETLM. Additionally, the entire Prepo Afloat process could be modeled stochastically, to reflect sea and weather conditions, port facilities, and unit preparation and training.

3. Usefulness of EETLM to the JTF Commander

a. In the planning phase of the operation

As mentioned above, in every case Red perceived that Blue was pursuing COA 3 until after attack time. If Red had the option to dynamically changes its COA, Red would have most probably chosen to pursue a COA which exploited Blue's COA 3. Armed with this knowledge, a commander and his staff could then better plan their COA. The COA chosen by the Blue commander could also be tested against the other possible Red COAs, to see how potentially robust the Blue COA might be. This information is obviously only as good as current intelligence and the model's ability to accurately represent perception changes. The possible impacts and outcomes of "What if" questions can also be simulated to develop alternate plans. This would facilitate the planning for many operational contingencies within a mission or campaign.

b. Enroute to the theater of operation

Intelligence officers often "fill in the blanks" about the enemy with assumptions or best guesses, based on their insight, training or intuition. Since intelligence gathering is a continual process, new information confirms, or denies assumptions, and provides further insights. As this new intelligence is made available to the commander, he can test the robustness of his selected COA to obtain an idea of the potential outcome. EETLM could be extremely useful to a commander enroute to a theater of operation for two reasons. First, once an early entry unit deploys, the travel time can be used to analyze outcomes, and second, intelligence usually becomes more available the closer the time is to mission execution.

c. Strength levels

From a planning perspective, a JTF commander would have an idea of what losses he might incur, what losses he should be prepared to incur, and what the consequences of those losses might be. Similarly, the commander will have an idea of the enemy strength levels at certain intervals in the conflict.

EETLM has the potential to model joint operations and can offer the JTF commander valuable insights as to the potential outcomes. EETLM can be used as a valuable planning and/or training tool, once a more mature version of the model is produced.

B. RECOMMENDATIONS

There are four main areas of recommendations: the dynamic nature of the joint model; the validation process; the war fighting capabilities; and the model as a training tool.

1. The Dynamic Nature of the Joint Model

EETLM needs to become more dynamic, in that all services should act in support of a specific theater level COA. Currently, the ground forces do, the Naval forces do (but to a much lesser extent) and the Air Forces do not. The Naval forces do support the theater COA; however, their actions are, for the most part, scripted and thus, support every theater COA in the same way. This does not provide much opportunity for the model to act on its perceptions of enemy COA, locations, or activities. Thereby, model dynamics for Naval operations are severely limited. Thus, all scripted missions and operations should be removed and dynamic logic and rule sets developed and implemented. The Air Force module dynamically supports the overall theater objective; however, it does not specifically support the theater COA. Missions, targets, and aircraft combinations are identified and dynamically selected to conduct deep strike, battlefield air interdiction, close air support, and air interdiction. The missions, targets, and aircraft combinations are not currently affected by the COA the theater is pursuing. Mission and target priorities will change between COAs, and this will affect the aircraft combinations selected to conduct the missions. These changes in mission and target priorities should be reflected in the Air Forces' support of a specific theater COA. It is recommended that, instead of implementing the Air module at the theater level, so it generically supports the overall theater objectives, the Air module should be implemented individually for each theater COA. This will allow the Air module to dynamically target prioritize, mission plan, and select optimal combinations of aircraft in detailed support of the priorities of a specific theater COA. This will eliminate the generic support to the theater.

2. The Verification Process

As mentioned in the thesis limitations, FTLM and EETLM are still in their infancy, as far as model development. To date, the emphasis of the model development has been to demonstrate the new stochastic modeling concepts. Rapid progress has been made in this effort. The major conceptual algorithms have been well thought out and are mathematically correct; however, they have not been verified to insure that they are operating correctly within the computer simulation. There are other algorithms currently operating within EETLM that are merely "place holder" algorithms, until more robust and detailed algorithms can be implemented. The attrition algorithm is an example of one such "place holder" algorithm. Currently, EETLM uses a simplistic attrition algorithm, which will be replaced by the ATCAL - COSAGE attrition process in the near future. The ATCAL - COSAGE attrition process is a well known and accepted attrition algorithm within the combat simulation community. [Ref. 19, PG. 134-142] Other algorithms in this category are the sensor detection, deep indirect fires, attack time, and sensor allocation. It is recommended that enhanced decision rule sets and algorithms be implemented. Once this is accomplished, an extensive verification and validation process should be conducted to insure correctness of all algorithms.

3. The War Fighting Capabilities

EETLM was conceived and developed with the idea of simulating joint theater level combat. Currently, only a limited number of critical war fighting capabilities are included. Other critical war fighting capabilities which should be modeled are mine warfare, anti - submarine warfare, Theater Ballistic Missile Defense (TBMD), Army aviation, and weapons of mass destruction. Mine warfare is becoming more and more critical to the Navy, due to its change in

mission from blue water to littoral operations. The Navy paid a heavy price in the Persian Gulf with mine strikes by the Samuel Roberts, Princeton, and the Tarawa. Even though the Soviet Navy threat has been reduced, there are many countries that have submarines. Iran and North Korea are two such countries, both of which are potential contingency areas. TBMD may be a spin-off from the Gulf War SCUD-busting efforts; however, a real threat exists and its impact should be considered when modeling theater level combat. Weapons of mass destruction (chemical, biological, and nuclear) fall into this same realm and should also be considered in EETLM. Again, this is not because the threat of a massive Soviet nuclear launch exists, but because countries like Iraq and North Korea possess weapons of mass destruction. Army aviation needs to be represented because it is another asset which the theater level commander has at his disposal (for both close combat and deep strike operations). Thus, it is recommended that the critical war fighting capabilities outlined above be incorporated in future versions of EETLM.

4. The Model as a Training Tool

EETLM is currently an analytical tool, however, there is interest from the Army and the Navy to also use EETLM as a training tool. Steps should be taken to provide an interactive wargame version of EETLM. This would increase the value of the model for a JTF commander, because it would give him more flexibility enroute for "what if" analysis and would also improve his mission planning for potential operations and staff training. At a macro level, the model could also be used at the Joint Chief of Staff's level and at the Senior Service Colleges for investigations into contingency operations, or potential conflicts.

VI. FUTURE RESEARCH

A. MULTIPLE UNITS ON A NODE

EETLM cannot account for more than one unit occupying a node (physical or transit) at any one time. The model is not equipped to distinguish between two or more units, or one larger unit (the combination of the two or more units).

In Ref. 14, pg. 27-28, Karl Schmidt describes a future improvement to FTLM concerning partitioning of nodes. Considering LTC Mark Youngren's paper [Ref. 20], the concept of physical node partitioning is to allow a parent unit to orient its sub-units (children) along certain transit nodes coming into the physical node. This is accomplished by allocating the sub-units to specific areas within the physical node directly in front of the transit nodes for which the sub-units are responsible, as shown in Figure 17.

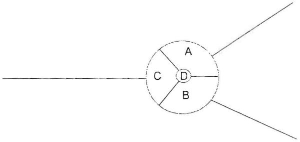


Figure 17. Node Partitioning

If this idea is extended to major units instead of sub-units, more than one major unit can exist on a physical node. The physical node would have to be either dynamically partitioned into the requisite number of sections, depending on the actual number of major units currently occupying

the physical node, or it would have to be initialized with a fixed number of sections. Fixing the number of sections would limit the number of major units able to occupy that physical node at any one time. By doing this, EETLM could then calculate the probabilities associated with each unit within a section of the node and those probabilities would feed the COA perceptions. Transit nodes could be handled in a similar manner and would allow for more than one unit to be on a system transit node, at any one time.

An alternative method for partitioning of nodes (both physical and transit) is to use several smaller nodes to represent the original, larger physical node, and connect each smaller node together with short transit nodes. In Figure 18 is an example of a smaller sub-nodes system comprising a main physical node.

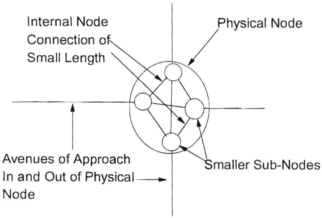


Figure 18. Sub-Node Partitioning

This would work for both physical and transit nodes. Effectively, this would allow for more than one unit to be on a node at any one time; however, it would increase the computation complexity of the model. EETLM would also be required to have the capability to dynamically

divide its units into sub-units, and apportion them on nodes in support of the desired friendly COA and the perceived enemy avenue of approach. EETLM would also have to reunite the sub-units for movement, or when necessary. This development can be explored once a more computationally capable platform is realized.

B. MINIMUM NUMBER OF FORWARD DEPLOYED TROOP UNITS

The initial focus of this thesis was to address this primary issue. Because joint theater level operations had not been previously modeled in a stochastic environment, EETLM was developed. New algorithms were introduced to allow for this maturation. As a result, the focus of this thesis is the documentation and the demonstration of these new capabilities. The problem statement was changed to demonstrate EETLM's capability to model and conduct joint theater level operations. The maturity level of the model did not permit the minimum force issue to be investigated. However, after validation, the number of combat units required to be forward deployed in a theater could be investigated. The approach to this analysis is outlined below.

If a specific number of forward deployed units can hold their positions, or delay long enough for reinforcements to arrive, then the question of whether or not the number of forward deployed units could be decreased and still hold their positions can be investigated. If the reinforcement/delay time is fixed, and the number of forward deployed units is incrementally decreased (incrementally increasing the reinforcing force), then the point at which the forward deployed forces will no longer be able to accomplish their delay mission can be determined. At that time, the forward deployed force would be below its minimum force size for accomplishing its mission. The forward deployed force size would have to be increased by one unit. After the increase, the forward deployed force would be at its minimum size. The actual magnitude of

increase would depend on many factors and would have to be investigated. The size increase is stochastic in nature and would certainly require a large number of replications to determine an optimal size of increase. Once this has been determined, the impact of reinforcement times and composition of the joint force could be investigated. For example, once the minimum forward deployed force size is determined, the impact of having one Aircraft Carrier Task Force with a Marine Assault Ready Group (ARG) in the immediate area, versus having two of these type task forces, or only having the 82nd ABN DIV on standby, or any combination, can be investigated. This may lead to a further reduction of the number of forward deployed forces. This analysis would focus on potential resource allocation tradeoffs and their impacts on the outcomes of theater operations.

C. COURSES OF ACTION

EETLM operates under the closed world assumption with regard to COAs. EETLM does not consider any COA not present in its database. There is no requirement to have the ground truth COA present in EETLM, however, all probability is distributed across the COAs that are represented. So, if the actual COA is not present, the COAs that are in the database will accumulate more probability than they should. In a planning situation, if strict operational security was enforced, and two planning staffs developed their own operation plans, to include friendly (Blue) and enemy (Red) COAs, based on current intelligence levels, it is conceivable that one or both sides would not have included the actual ground truth COA of the other in its selections of enemy COAs. So as the simulation unfolded, the model would distribute the probability over the available COAs. Obviously, the actual enemy ground truth COA would not receive any probability, because it would not exist, as far as that particular side is concerned. The

COA which matched the actual ground truth COA the closest would receive most of the probability, and the other COAs would receive the rest. The closer a COA resembled the actual ground truth COA, based on sensor accuracy and information available, the more probability it would receive. The benefit of this result might be increased if, in that same situation described above, a COA category labeled "others" or "not considered" was automatically added to both sides to capture the probability of the actual ground truth COA, if not considered. Doing so would eliminate either side from knowing the actual ground truth COA of the other, without having developed it through their own intelligence and mission analysis process. This would allow for more realistic planning. The computer would obviously still know all enemy COAs on both sides, and would continue to assess probability based on the sensor observations. If the actual enemy COA was not part of one side's potential enemy COA list, the "other COAs" would receive the probability, instead of it being distributed among the other COAs according to similarity. This would facilitate EETLM's use as a training tool for commanders and their staff's when conducting war gaming or mission analysis. An excluded COA, or one bearing little or no resemblance to an actual COA, might be indicative of faulty assumptions, logic, mission planning, or intelligence.

Another issue is the setting of the initial COA perceptions. Currently, the model does this automatically for the user. All COAs perceptions are assumed to be equally likely until the first COA update. The user should have the flexibility to initially input the COA perception probabilities in the database.

A third issue which should be included in the mature EETLM is dynamic COA selection by both attacker and defender. One of the model limitations discussed in Chapter I is that once a

COA is selected by the defender, it remains fixed and cannot be dynamically shifted to another COA during model execution, even if the perception of that COA is extremely low. The attacker's COA selection is also fixed. Another factor is that, within a COA, there are no methods to shift from a defensive to an offensive posture, or vice versa. There are some specific missions which do, in fact, dictate purely defensive operations. However, in a theater level operation, the missions may include both defensive and offensive operations.

EETLM can model joint operations and can be valuable in planning and wargaming operations. With the above mentioned recommendations for improvement and future work, EETLM can and will be instrumental in joint operations, now and in the future.

APPENDIX A. GROUND COURSES OF ACTION

General. Red has three viable courses of action (COAs). All COAs involve a logistical build-up of supplies well forward to support a massive offensive into South Korea. The intermediate objectives are Seoul, Suwon, and the surrounding road network, with the final objectives being Kunsan, Taegu, Pusan, Kwangju, and Pohang. Each Red COA has a single corresponding Blue COA to counter it.

A. COA 1

1. RED COA 1

This COA involves a 15 Division attack along the Western and Eastern corridors. At the commencement of hostilities, Haeju, Pyongyang, P'Yonggang, Wonsan, and Kosong will all have three divisions (each with 4 Brigades) attacking from their respective locations:

Haeju	Division 1,	4 Brigades	4 Log Units
	Division 2,	4 Brigades	4 Log Units
	Division 3	4 Brigades	4 Log Units
Pyongyang	Division 4	4 Brigades	4 Log Units
	Division 5	4 Brigades	4 Log Units
	Division 6	4 Brigades	4 Log Units
Wonsan	Division 7	4 Brigades	4 Log Units
	Division 8	4 Brigades	4 Log Units
	Division 9	4 Brigades	4 Log Units
P'Yonggang	Division 10	4 Brigades	4 Log Units
	Division 11	4 Brigades	4 Log Units
	Division 12	4 Brigades	4 Log Units
Kosong	Division 13	4 Brigades	4 Log Units
	Division 14	4 Brigades	4 Log Units

Division 15	4 Brigades	4 Log Units

Prior to these combat units arriving and hostilities commencing, the Log Units will arrive. For ground truth, the Logistical Units are scheduled into their respective nodes at a rate which will insure all required logistical support is in position by SIMTIME = 6.00. SIMTIME is the simulation time and is kept by the internal clock of the computer. It is started at the beginning of the simulation. Currently, one unit of time is defined as one day. After the Log Units are in position (SIMTIME =6.00), the combat units will arrive at their respective nodes and commence hostilities. The Red attack will commence at SIMTIME = 6.00.

Phase 1. Divisions 1,4,7,10,13 from their respective nodes will attack to seize the following objective: Seoul, Kimhwa, Chunchon, Munsan (Chorwon), Kangnung (Kansong).

Phase 2. Divisions 2,5,8,11,14 from their respective nodes attack to seize the following objectives: Kongju, Wonju, Taejon, Suwon, Samchok.

Phase 3. Divisions 3,6,9,12,15 from their respective nodes attack to seize the following objectives: Kunsan, Kwangju, Pusan, Taegu, Pohang.

2. BLUE COA 1

Blue conducts purely defensive operations. Prior to hostilities Blue forces are positioned in the following locations:

Group.1-1	Armor	4 Brigades	Munsan	In country
Group.1-2	Mechanized	4 Brigades	Wonju	In country
Group.1-3	Infantry	4 Brigades	Kangnung	In country
Group.2-1	Armor	4 Brigades	Seoul	In country
Group.2-2	Armor	4 Brigades	Pusan	In country
Group.2-3	Infantry	4 Brigades	Chunchon	In country
Group.3-1	Mechanized	4 Brigades	Suwon	In country
Group.3-2	Mechanized	4 Brigades	Kimhwa	In country
Group.3-3	Infantry	4 Brigades	Kansong	In country
Group.3-4	Infantry	4 Brigades	Chorwon	In country

Group.4-1	Armor	3 Brigades	Kunsan	Arrives at or prior to invasion
Group.4-2	Armor	3 Brigades	Kongju	Arrives at or prior to invasion
Group.4-3	Airborne	4 Brigades	Kwangju	Arrives at or prior to invasion
Group.4-4	Air Assault	3 Brigades	Yongdok	Arrives at or prior to invasion
Group.4-5	Armor	3 Brigades	Chonju	Arrives at or prior to invasion
Group.4-6	Armor	3 Brigades	Pohang	Arrives at or prior to invasion
Group.4-7	Marine	4 Brigades	Taegu	Arrives at or prior to invasion
Group.4-8	Marine	4 Brigades	Taejon	Arrives at or prior to invasion

B. COA 2

1. RED COA 2

This COA involves a 11 Division attack along the Western and Central corridors. At the commencement of hostilities, Haeju, Pyongyang, P'Yonggang, Wonsan, and Kosong will have the following Divisions, (each with 4 Brigades) attacking from their respective locations:

Haeju	Division 1,	4 Brigades	4 Log Units
	Division 2,	4 Brigades	4 Log Units
	Division 7	4 Brigades	4 Log Units
	Division 10	4 Brigades	4 Log Units
Pyongyang	Division 4	4 Brigades	4 Log Units
	Division 5	4 Brigades	4 Log Units
	Division 12	4 Brigades	4 Log Units
	Division 13	4 Brigades	4 Log Units
	Division 14	4 Brigades	4 Log Units
Wonsan	Division 8	4 Brigades	4 Log Units
	Division 9	4 Brigades	4 Log Units
	Division 11	4 Brigades	4 Log Units
	Division 15	4 Brigades	4 Log Units
P'Yonggang	Division 3	4 Brigades	4 Log Units
	Division 6	4 Brigades	4 Log Units
Kosong	NONE		

Prior to these combat units arriving and hostilities commencing, the Log Units will arrive. The Log Units are scheduled into their respective nodes at a rate which will insure all

required logistical support is in position by SIMTIME = 6.00. After the Log Units are in position (SIMTIME =6.00), the combat units will arrive at their respective nodes and commence hostilities.

Phase 1. Divisions 1,10,3,6,11 from their respective nodes will attack to seize the following objective: Seoul, Munsan, Kunsan, Wonju, Suwon. Divisions 4,5,12,14 are in reserve at Pyongyang.
Phase 2. Divisions 2,7,8,13 from their respective nodes attack to seize the following objectives: Taejon, Kwangju, Taegu, Chungju.
Phase 3. Divisions 9,15 from their respective nodes attack to seize the following objectives: Pusan, Pohang.

2. BLUE COA 2

Blue conducts purely defensive operations. Prior to hostilities Blue forces are positioned in the following locations:

Group.1-1	Armor	4 Brigades	Munsan	In country
Group.1-2	Mechanized	4 Brigades	Wonju	In country
Group.1-3	Infantry	4 Brigades	Kangnung	In country
Group.2-1	Armor	4 Brigades	Seoul	In country
Group.2-2	Armor	4 Brigades	Pusan	In country
Group.2-3	Infantry	4 Brigades	Chunchon	In country
Group.3-1	Mechanized	4 Brigades	Suwon	In country
Group.3-2	Mechanized	4 Brigades	Kimhwa	In country
Group.3-3	Infantry	4 Brigades	**Chungju**	In country
Group.3-4	Infantry	4 Brigades	Chorwon	In country
Group.4-1	Armor	3 Brigades	Kunsan	Arrives at or prior to invasion
Group.4-2	Armor	3 Brigades	Kongju	Arrives at or prior to invasion
Group.4-3	Airborne	4 Brigades	Kwangju	Arrives at or prior to invasion
Group.4-4	Air Assault	3 Brigades	Yongdok	Arrives at or prior to invasion
Group.4-5	Armor	3 Brigades	Chonju	Arrives at or prior to invasion
Group.4-6	Armor	3 Brigades	Pohang	Arrives at or prior to invasion
Group.4-7	Marine	4 Brigades	Taegu	Arrives at or prior to invasion
Group.4-8	Marine	4 Brigades	Taejon	Arrives at or prior to invasion

C. COA 3

1. RED COA 3

This COA involves a 15 Division attack along 3 corridors: a Western, Central, and Eastern. At the commencement of hostilities, Haeju, Pyongyang, P'Yonggang, Wonsan, and Kosong will have the following Divisions (each with 4 Brigades) attacking from their locations:

Haeju	Division 5,	4 Brigades	4 Log Units
	Division 7,	4 Brigades	4 Log Units
	Division 15	4 Brigades	4 Log Units
Pyongyang	Division 1	4 Brigades	4 Log Units
	Division 2	4 Brigades	4 Log Units
	Division 4	4 Brigades	4 Log Units
	Division 6	4 Brigades	4 Log Units
	Division 8	4 Brigades	4 Log Units
	Division 9	4 Brigades	4 Log Units
	Division 10	4 Brigades	4 Log Units
Wonsan	Division 3	4 Brigades	4 Log Units
	Division 11	4 Brigades	4 Log Units
	Division 12	4 Brigades	4 Log Units
	Division 13	4 Brigades	4 Log Units
	Division 15	4 Brigades	4 Log Units
P'Yonggang	NONE		
Kosong	NONE		

Prior to these combat units arriving and hostilities commencing, the Log Units will arrive. The Log Units are scheduled into their respective nodes at a rate which will insure all required logistical support is in position by SIMTIME = 6.00. After the Log Units are in position (SIMTIME =6.00), the combat units will arrive at their respective nodes and commence hostilities.

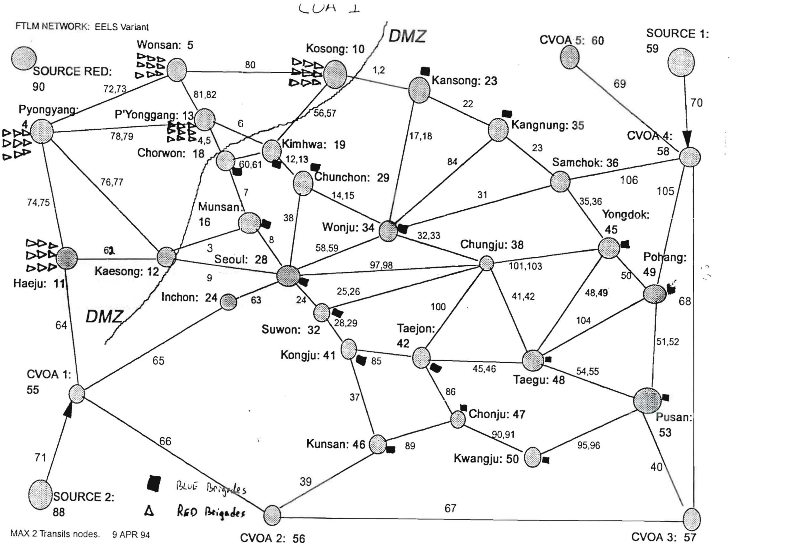
Phase 1. Divisions 3, 4, 5,10,14 from their respective nodes will attack to seize the following objective: Seoul, Kimhwa, Chunchon, Munsan (Chorwon), Samchok.
Phase 2. Divisions 11,12 from their respective nodes attack to seize the following objectives: Suwon, Kongju.

Phase 3. Divisions 1, 2, 6, 7, 8, 9, 13, 15 from their respective nodes attack to seize the following objectives: Kunsan, Taejon, Wonju, Kwangju, Taegu, Pusan, Chungju, Pohang.

2. BLUE COA 3

Blue conducts purely defensive operations. Prior to hostilities Blue forces are positioned in the following locations:

Group.1-1	Armor	4 Brigades	Munsan	In country
Group.1-2	Mechanized	4 Brigades	Wonju	In country
Group.1-3	Infantry	4 Brigades	Kangnung	In country
Group.2-1	Armor	4 Brigades	Seoul	In country
Group.2-2	Armor	4 Brigades	Pusan	In country
Group.2-3	Infantry	4 Brigades	Chunchon	In country
Group.3-1	Mechanized	4 Brigades	Suwon	In country
Group.3-2	Mechanized	4 Brigades	Kimhwa	In country
Group.3-3	Infantry	4 Brigades	Kansong	In country
Group.3-4	Infantry	4 Brigades	Chorwon	In country
Group.4-1	Armor	3 Brigades	Kunsan	Arrives at or prior to invasion
Group.4-2	Armor	3 Brigades	Kongju	Arrives at or prior to invasion
Group.4-3	Airborne	4 Brigades	Kwangju	Arrives at or prior to invasion
Group.4-4	Air Assault	3 Brigades	Yongdok	Arrives at or prior to invasion
Group.4-5	Armor	3 Brigades	**Taejon**	Arrives at or prior to invasion
Group.4-6	Armor	3 Brigades	Pohang	Arrives at or prior to invasion
Group.4-7	Marine	4 Brigades	**Samchok**	Arrives at or prior to invasion
Group.4-8	Marine	4 Brigades	**Chungju**	Arrives at or prior to invasion



COA 1
FTLM NETWORK: EELS Variant
SOURCE RED: 90
Wonsan: 5
Kosong: 10
DMZ
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kansong: 23
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
DMZ
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
BLUE Brigades
RED Brigades
CVOA 2: 56
CVOA 3: 57
MAX 2 Transits nodes. 9 APR 94
80
1,2
69
70
72,73
81,82
56,57
22
78,79
6
4,5
17,18
23
60,61
12,13
84
106
76,77
7
14,15
31
35,36
105
74,75
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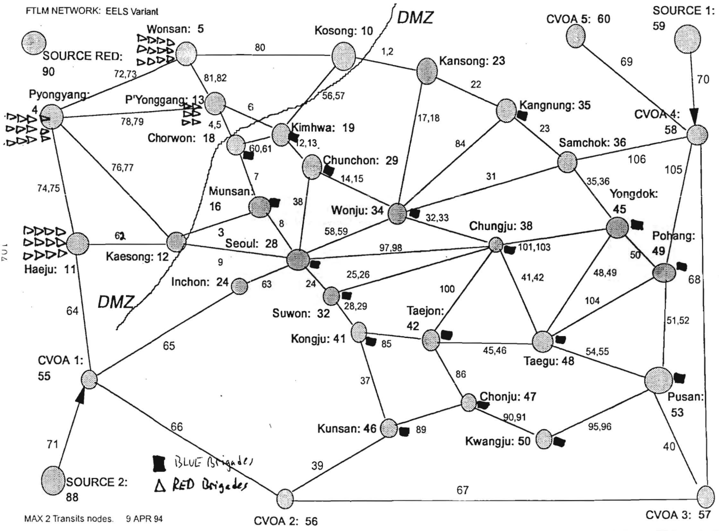
32,33
8
58,59
62
3
97,98
101,103
50
9
25,26
41,42
48,49
68
63
24
100
104
64
28,29
51,52
65
85
45,46
54,55
37
86
66
90,91
71
89
95,96
40
39
67

COA II


FTLM NETWORK: EELS Variant
SOURCE RED: 90
Wonsan: 5
Kosong: 10
DMZ
Kansong: 23
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Chungju: 38
Pohang: 49
Kaesong: 12
Seoul: 28
Haeju: 11
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
BLUE Brigades
RED Brigades
CVOA 2: 56
CVOA 3: 57
80
1,2
72,73
81,82
22
69
70
6
56,57
78,79
4,5
17,18
23
12,13
60,61
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100
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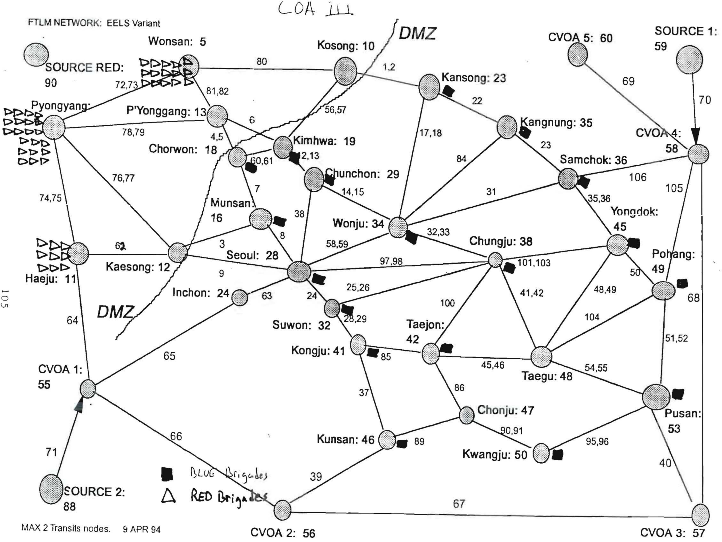
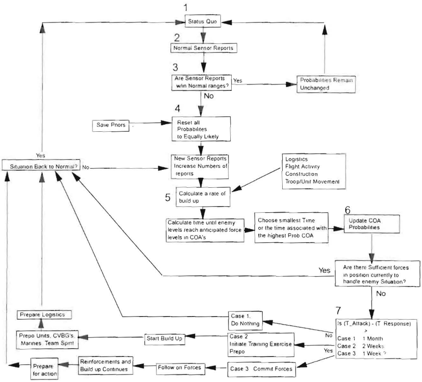
64
51,52
85
45,46
54,55
65
86
37
90,91
66
89
95,96
71
40
39
67
MAX 2 Transits nodes. 9 APR 94


COA III
FTLM NETWORK: EELS Variant
DMZ
Wonsan: 5
Kosong: 10
CVOA 5: 60
SOURCE 1: 59
SOURCE RED: 90
Kansong: 23
Pyongyang:
P'Yonggang: 13
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Samchok: 36
Chunchon: 29
Munsan: 16
Wonju: 34
Yongdok: 45
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Haeju: 11
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
BLUE Brigades
RED Brigades
CVOA 2: 56
CVOA 3: 57
MAX 2 Transits nodes. 9 APR 94

APPENDIX B. LOGISTICAL DECISION FLOWCHART



APPENDIX C. EXAMPLE

Area of interest contains three nodes: nodes 1,2, and 3. Status quo is defined as the following:

Node 1: 1 Armor Brigade present (1,0,0); 1 Logistics Unit present.

Node 2: 1 Mechanized Brigade present (0,1,0); 1 Logistics Unit present.

Node 3: 1 Infantry Brigade present (0,0,1); 1 Logistics Unit present.

COA 1: Composition	(2,1,1) total = 4 Bde;	Attack (nodes 1-5-8).
	(0,0,2) total = 2 Bde;	Defend (at node 2)
	(2,0,2) total = 4 Bde;	Attack (nodes 3-7-8)
COA 2: Composition	(1,0,1) total = 2 Bde;	Defend (at node 1)
	(1,2,1) total = 4 Bde;	Attack (nodes 2-6-8)
	(0,3,1) total = 4 Bde;	Attack (nodes 3-7-8)
COA 3: Composition	(1,2,1) total = 4 Bde;	Attack (nodes 1-5-8)
	(1,2,1) total = 4 Bde;	Attack (nodes 2-6-8)
	(0,1,1) total = 2 Bde;	Defend (at node 3)

-Sensors report an increase of Logistics Units. A deviation of one additional Logistics Unit on any node triggers a reset of all COAs.

-All COAs are reset to equally likely.

-Sensor sweeps are increased.

-Over a delta time period of one week, total log unit increase in the area of interest (nodes 1, 2, and 3) was 5 log units. Therefore the overall log rate of increase for the area of interest is 5 log

units per week.

-The minimum total number of Bde size units required for any COA is 10 Bde. Therefore the

Time of Attack is 10 Bde / 5 Bde per week = 2 weeks. This is Blue's perception of when Red will attack.

-The Logistics Unit increase at each node was sensed as the following:

Node 1: 2 Logistics Unit increase

Node 2: 2 Logistics Unit increase

Node 3: 1 Logistics Unit increase

-Predicted Bde units at Time of Attack: Time of Attack x Individual Log rate = Number of units

Node 1: 2 x 2 = 4 Bde at node 1 at Time of Attack.

Node 2: 2 x 2 = 4 Bde at node 2 at Time of Attack.

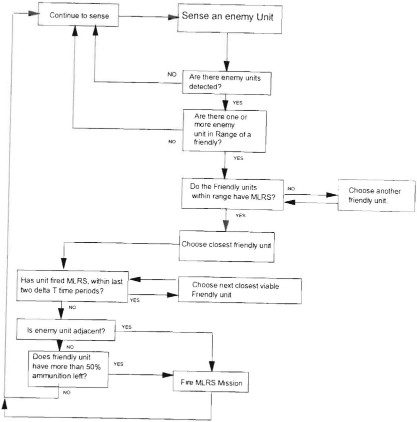
Node 3: 2 x 1 = 2 Bde at node 3 at Time of Attack.

-These numbers of Bdes would then be used to drive the COA probabilities. In this example, COA 3 would match up and would receive the highest probability.

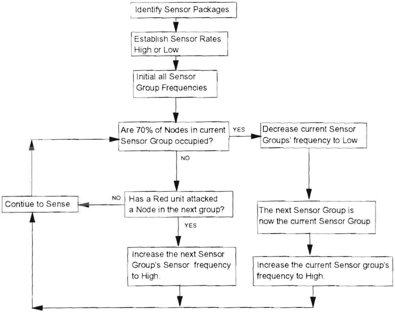
-If the Required Response Time to provide sufficient forces in theater is 1 week, then the decision to commit forces must/will be made in 1 week.

-The Early Entry Force will execute their COA which corresponds to the Red COA that has the highest probability associated with it (the greater of the probabilities determined by the Logistics units and the combat units).

APPENDIX D. INDIRECT FIRES FLOWCHART



APPENDIX E. SENSOR ALLOCATION FLOWCHART



APPENDIX F. DATA SOURCE MATRIX

GROUND TRUTH RED COA 1															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance
(BLUE END STRENGTH) / (START STRENGTH)															
(RED END STRENGTH) / (START STRENGTH)															
(BLUE END STRENGTH) / (RED END STRENGTH)															
GROUND TRUTH RED COA 2															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)															
(RED END STRENGTH) / (START STRENGTH)															
(BLUE END STRENGTH) / (RED END STRENGTH)															
GROUND TRUTH RED COA 3															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)															
(RED END STRENGTH) / (START STRENGTH)															
(BLUE END STRENGTH) / (RED END STRENGTH)															

APPENDIX G. DATA

Each Red COA is displayed in a separate table, in Tables G-1 through G-3, . Each table is further subdivided into two parts. The upper half contains the strength results of the Blue force, while the bottom half contains the Red strength results. Column two, row one, of the matrix indicates the applicable side. The strength results, pertaining to a specific side, are reported by entry case and by replication number. In column three of the matrix, Blue's response COA is recorded, by case and replication. The data for air and naval strengths are given in [Ref. 2]. Figures G-4 through G-12 show the Red penetration into South Korea, for each Red COA and Blue entry case.

GROUND TRUTH RED COA 1	BLUE	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	1	64946	202042	15744	24700	60989	188500	1529	5250				
	REP 2	1	52523	202042	15042	24700	49219	188500	1234	5250				
	REP 3	1	52523	202042	15041	24700	49220	188500	1234	5250				
CASE 2	REP 1	1	103420	202042	15943	24700	96772	188500	3134	5250				
	REP 2	1	93128	202042	15344	24700	87329	188500	2893	5250				
	REP 3	1	101043	202042	15943	24700	94480	188500	3134	5250				
CASE 3	REP 1	1	52724	202042	15040	24700	49403	188500	1242	5250				
	REP 2	1	83218	202042	17244	24700	77141	188500	2358	5250				
	REP 3	1	60419	202042	15642	24700	56353	188500	1473	5250				

GROUND TRUTH RED COA 1	RED	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	1	57933	207988	11008	16800	57163	202400	18	320				
	REP 2	1	124299	207988	13197	16800	121338	202400	202	320				
	REP 3	1	124303	207988	13187	16800	121342	202400	205	320				
CASE 2	REP 1	1	45788	207988	11337	16800	45142	202400	18	320				
	REP 2	1	45784	207988	11004	16800	45137	202400	18	320				
	REP 3	1	45796	207988	11331	16800	45157	202400	18	320				
CASE 3	REP 1	1	99179	207988	13133	16800	96560	202400	200	320				
	REP 2	1	86652	207988	12152	16800	84183	202400	202	320				
	REP 3	1	99185	207988	12753	16800	96551	202400	204	320				

Table G-1. Data Table

GROUND TRUTH RED COA 2	BLUE	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	2	60511	202042	15640	24700	56450	188500	1469	5250				
	REP 2	2	60513	202042	15639	24700	56446	188500	1474	5250				
	REP 3	2	83471	202042	17239	24700	77383	188500	2359	5250				
CASE 2	REP 1	1	87270	202042	14691	24700	82356	188500	2501	5250				
	REP 2	1	66958	202042	14739	24700	63135	188500	1756	5250				
	REP 3	1	87843	202042	14689	24700	82929	188500	2501	5250				
CASE 3	REP 1	1	72479	202042	16287	24700	67975	188500	1616	5250				
	REP 2	1	72311	202042	16287	24700	67824	188500	1611	5250				
	REP 3	1	72489	202042	16288	24700	67985	188500	1616	5250				

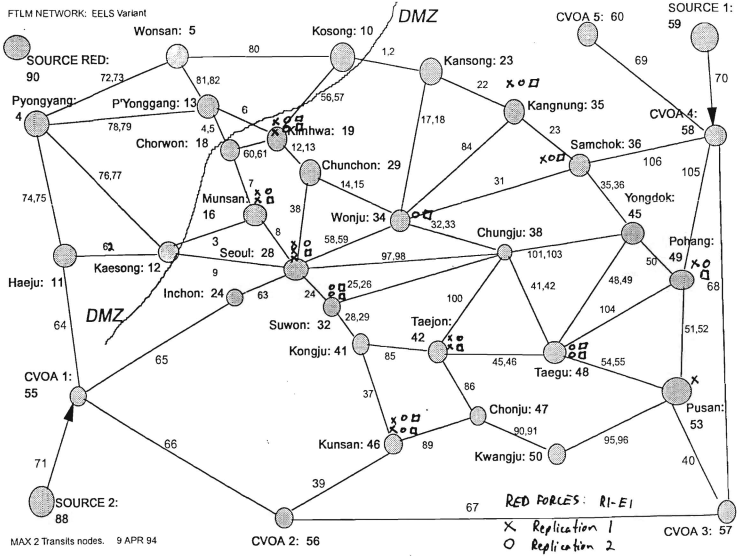
GROUND TRUTH RED COA 2	RED	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	2	121251	207988	13029	16800	119566	202400	20	320				
	REP 2	2	121255	207988	13038	16800	119571	202400	20	320				
	REP 3	2	108625	207988	12896	16800	107152	202400	19	320				
CASE 2	REP 1	1	120943	207988	13296	16800	119288	202400	15	320				
	REP 2	1	120932	207988	12883	16800	119279	202400	15	320				
	REP 3	1	120927	207988	13282	16800	119272	202400	15	320				
CASE 3	REP 1	1	121208	207988	12493	16800	119574	202400	17	320				
	REP 2	1	121232	207988	12922	16800	119590	202400	17	320				
	REP 3	1	120846	207988	12853	16800	119233	202400	15	320				

Table G-2. Data Table

GROUND TRUTH RED COA 3	BLUE	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	2	79229	202042	17134	24700	73014	188500	2312	5250				
	REP 2	2	79226	202042	17135	24700	73014	188500	2312	5250				
	REP 3	2	79237	202042	17137	24700	73017	188500	2312	5250				
CASE 2	REP 1	2	79857	202042	14387	24700	75067	188500	2317	5250				
	REP 2	2	80328	202042	14386	24700	75523	188500	2317	5250				
	REP 3	1	71796	202042	13940	24700	67171	188500	2315	5250				
CASE 3	REP 1	2	79228	202042	17135	24700	73015	188500	2313	5250				
	REP 2	2	79226	202042	17136	24700	73017	188500	2310	5250				
	REP 3	2	79241	202042	17140	24700	73015	188500	2315	5250				

GROUND TRUTH RED COA 3	RED	BLUE RESPONSE COA	END GROUND STRENGTH	START GROUND STRENGTH	END LOG STRENGTH	START LOG STRENGTH	END PERSONNEL STRENGTH	START PERSONNEL STRENGTH	END IFV STRENGTH	START IFV STRENGTH	END AIR STRENGTH	START AIR STRENGTH	END NAVAL STRENGTH	START NAVAL STRENGTH
CASE 1	REP 1	2	58543	207988	11293	16800	57626	202400	17	320				
	REP 2	2	58534	207988	11292	16800	57618	202400	17	320				
	REP 3	2	58548	207988	11293	16800	57631	202400	17	320				
CASE 2	REP 1	2	58574	207988	10896	16800	57654	202400	17	320				
	REP 2	2	58572	207988	10897	16800	57651	202400	17	320				
	REP 3	1	58547	207988	11280	16800	57628	202400	17	320				
CASE 3	REP 1	2	58533	207988	11298	16800	57615	202400	17	320				
	REP 2	2	58542	207988	11289	16800	57623	202400	17	320				
	REP 3	2	58546	207988	11280	16800	57627	202400	17	320				

Table G-3. Data Table



FTLM NETWORK: EELS Variant
DMZ
SOURCE RED: 90
Wonsan: 5
Kosong: 10
Kansong: 23
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Chungju: 38
Pohang: 49
Haeju: 11
Kaesong: 12
Seoul: 28
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
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1,2
72,73
81,82
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64
28,29
51,52
85
45,46
54,55
65
86
37
90,91
89
95,96
66
71
39
40
67
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R1-E1
X Replication 1
O Replication 2
☐ Replication 3

Figure G-4

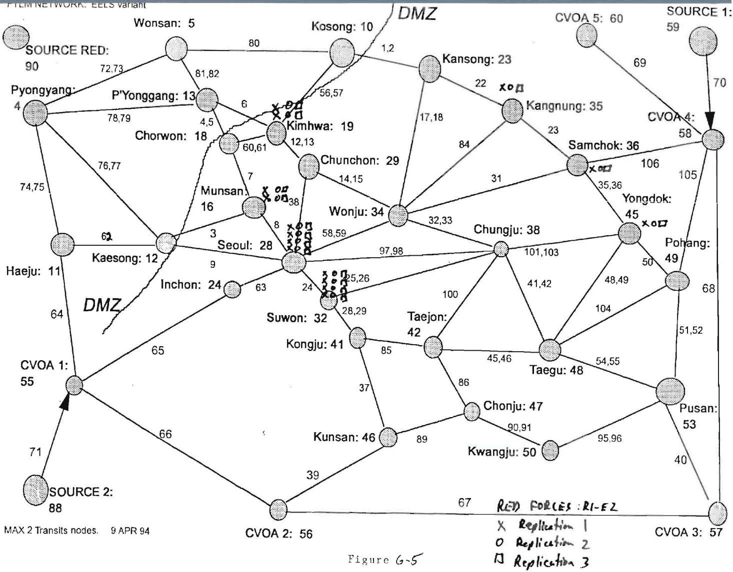
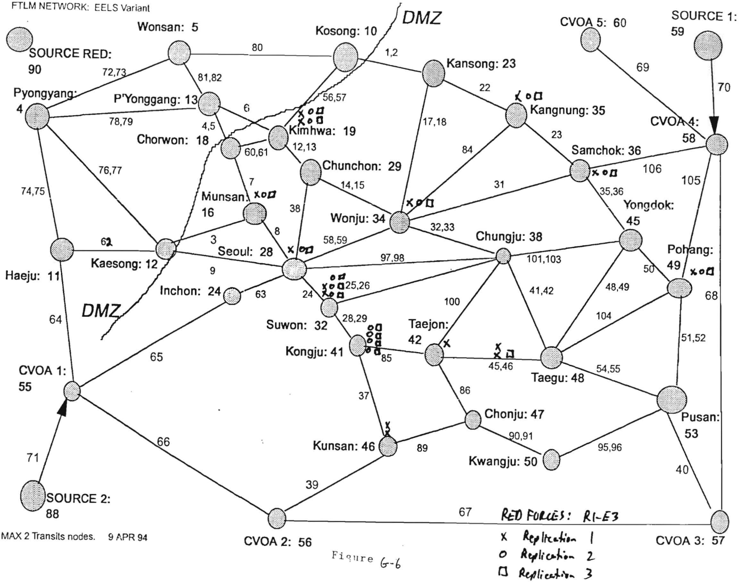

FTLM NETWORK: EELS variant
DMZ
SOURCE RED: 90
Wonsan: 5
Kosong: 10
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kansong: 23
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Samchok: 36
Chunchon: 29
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
CVOA 1: 55
Taegu: 48
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R1-E2
X Replication 1
O Replication 2
◻ Replication 3

Figure 6-5


FTLM NETWORK: EELS Variant
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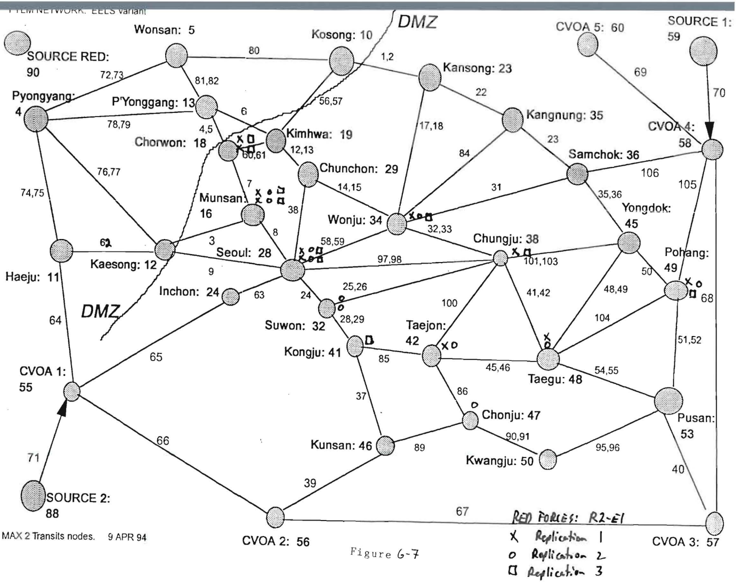
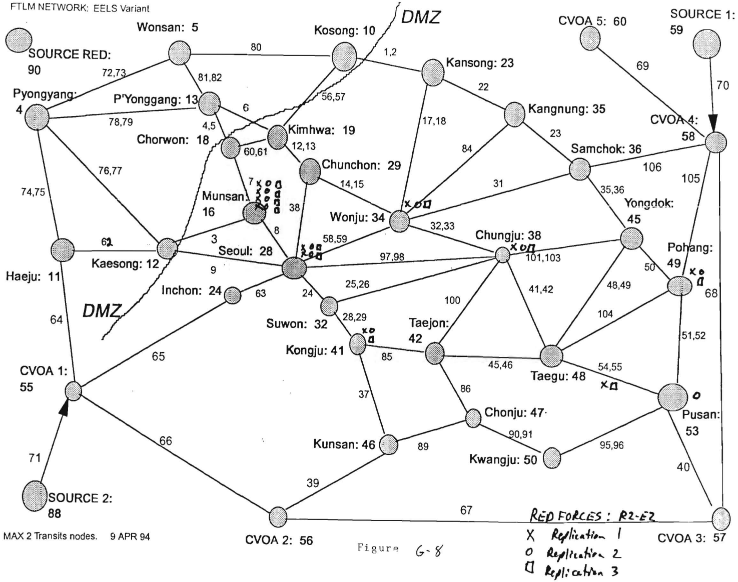
SOURCE RED: 90
Wonsan: 5
Kosong: 10
Kansong: 23
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kimhwa: 19
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Chungju: 38
Pohang: 49
Haeju: 11
Kaesong: 12
Seoul: 28
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R1-E3
x Replication 1
o Replication 2
□ Replication 3

Figure G-6



TTEM NETWORK: EELS variant
DMZ
Wonsan: 5
Kosong: 10
CVOA 5: 60
SOURCE 1: 59
SOURCE RED: 90
Kansong: 23
Pyongyang: 4
P'Yonggang: 13
Kangnung: 35
CVOA 4: 58
Kimhwa: 19
Chorwon: 18
Samchok: 36
Chunchon: 29
Munsan: 16
Wonju: 34
Yongdok: 45
Chungju: 38
Pohang: 49
Seoul: 28
Kaesong: 12
Haeju: 11
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
CVOA 1: 55
Taegu: 48
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
80
1,2
72,73
81,82
56,57
22
69
70
78,79
6
17,18
4,5
12,13
23
60,61
84
76,77
106
74,75
7
14,15
31
105
35,36
38
62
3
8
58,59
32,33
9
97,98
101,103
50
25,26
24
63
100
41,42
48,49
68
64
28,29
104
65
85
45,46
51,52
54,55
37
86
66
89
90,91
95,96
71
39
40
67
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R2-E1
X Replication 1
O Replication 2
□ Replication 3

Figure 6-7



FTLM NETWORK: EELS Variant
SOURCE RED: 90
Wonsan: 5
Kosong: 10
DMZ
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kimhwa: 19
Kansong: 23
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Pusan: 53
Chonju: 47
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
DMZ
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R2-E2
X Replication 1
O Replication 2
□ Replication 3

Figure G-8

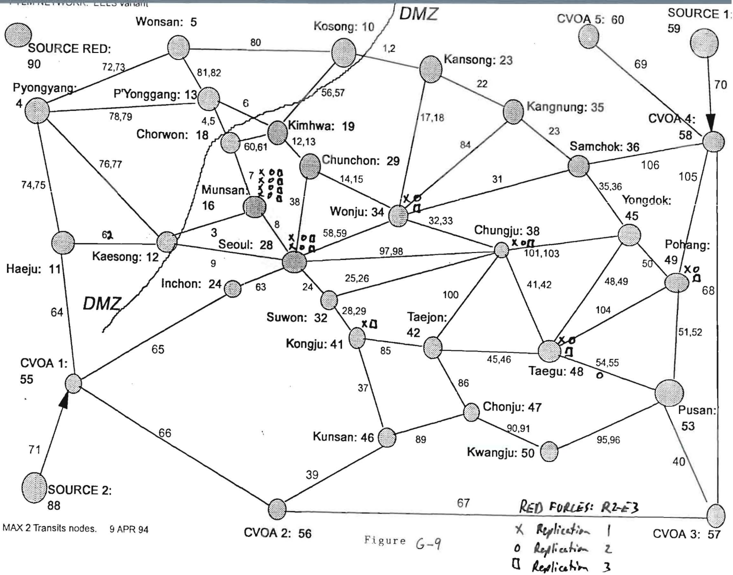
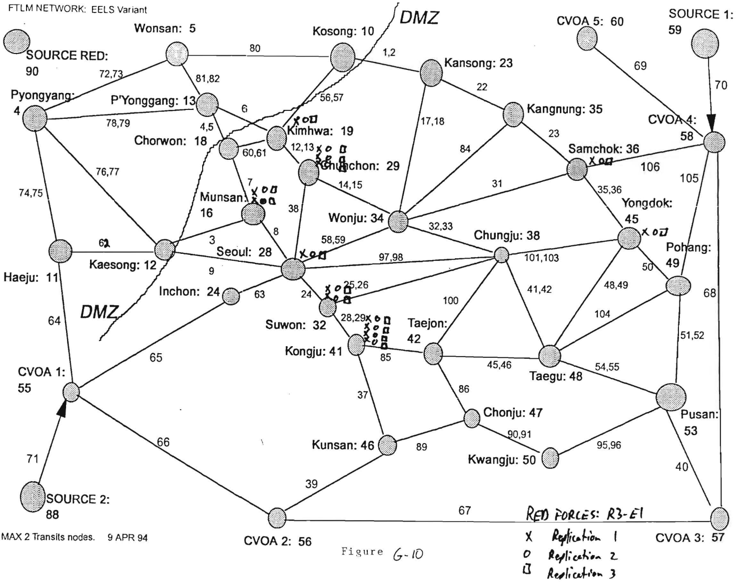

DMZ
SOURCE RED: 90
Wonsan: 5
Kosong: 10
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kansong: 23
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Samchok: 36
Chunchon: 29
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
80
1,2
72,73
81,82
22
56,57
6
78,79
17,18
4,5
23
69
70
12,13
60,61
84
76,77
74,75
7
38
14,15
31
106
105
35,36
8
62
3
58,59
32,33
9
97,98
101,103
50
24
25,26
63
64
100
41,42
48,49
68
28,29
104
65
85
45,46
54,55
51,52
37
86
66
71
89
90,91
95,96
40
39
67
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R2-E3
X Replication 1
O Replication 2
◻ Replication 3

Figure G-9



FTLM NETWORK: EELS Variant
DMZ
SOURCE RED: 90
Wonsan: 5
Kosong: 10
Kansong: 23
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kimhwa: 19
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
MAX 2 Transits nodes. 9 APR 94
80
72,73
81,82
1,2
22
69
70
56,57
78,79
6
4,5
17,18
23
60,61
12,13
84
106
76,77
14,15
31
105
74,75
7
35,36
38
32,33
8
58,59
3
62
97,98
101,103
9
50
25,26
63
24
100
41,42
48,49
64
28,29
104
68
51,52
85
65
45,46
54,55
86
37
90,91
66
89
95,96
71
40
39
67
RED FORCES: R3-E1
X Replication 1
O Replication 2
□ Replication 3

Figure G-10

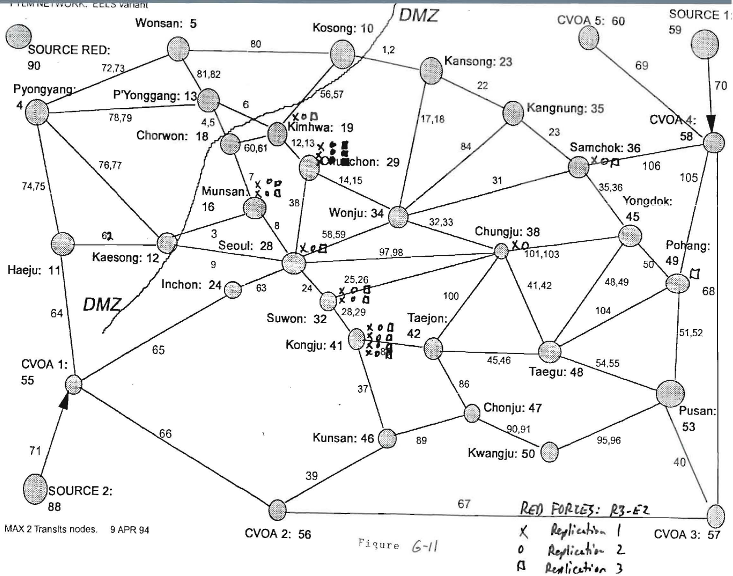
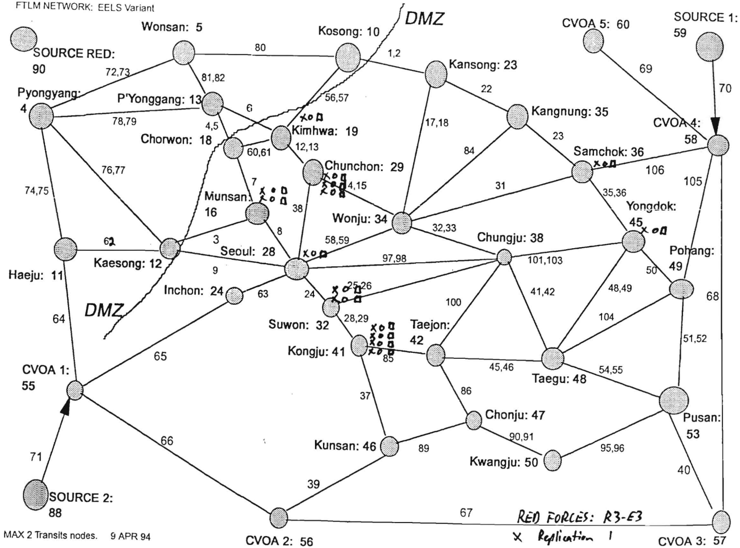


Figure 6-11

127


FTLM NETWORK: EELS Variant
SOURCE RED: 90
Wonsan: 5
Kosong: 10
DMZ
CVOA 5: 60
SOURCE 1: 59
Pyongyang: 4
P'Yonggang: 13
Kansong: 23
Kangnung: 35
CVOA 4: 58
Chorwon: 18
Kimhwa: 19
Chunchon: 29
Samchok: 36
Munsan: 16
Wonju: 34
Yongdok: 45
Haeju: 11
Kaesong: 12
Seoul: 28
Chungju: 38
Pohang: 49
Inchon: 24
Suwon: 32
Taejon: 42
Kongju: 41
Taegu: 48
DMZ
CVOA 1: 55
Chonju: 47
Pusan: 53
Kunsan: 46
Kwangju: 50
SOURCE 2: 88
CVOA 2: 56
CVOA 3: 57
80
72,73
81,82
1,2
56,57
22
69
70
78,79
6
4,5
17,18
23
60,61
12,13
84
106
105
76,77
74,75
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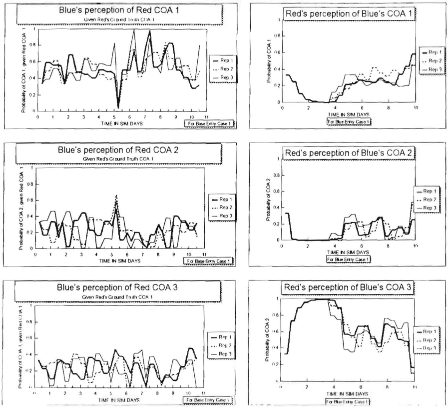
4,15
31
35,36
38
8
32,33
58,59
3
62
97,98
101,103
50
9
25,26
63
24
100
41,42
48,49
68
64
28,29
104
51,52
65
45,46
54,55
85
37
86
66
90,91
89
95,96
71
40
39
67
MAX 2 Transits nodes. 9 APR 94
RED FORCES: R3-E3
X Replication 1
O Replication 2
□ Replication 3

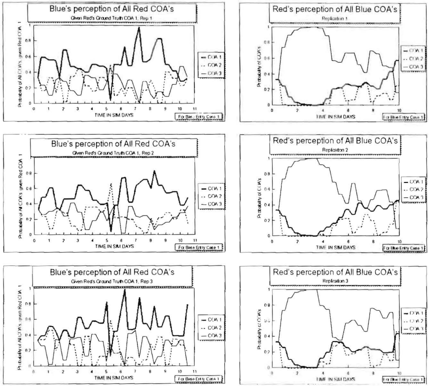
Figure G-12

APPENDIX H. GRAPHS

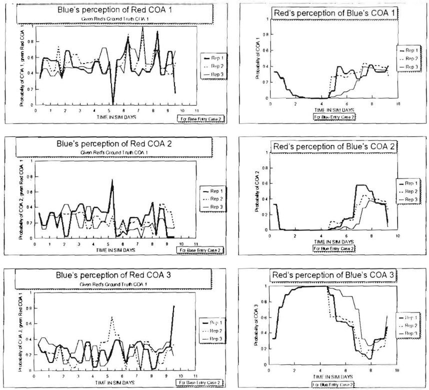
The graph set is titled by ground truth Red COA and Blue entry case (e.g., a title of R1-E1 means Red in ground truth pursues its COA 1 and Blue conducts entry case 1). Each set contains twelve graphs. Within each set, the data were separated into two categories. Category one (first page of graph set) displays the data by COA across the three replications, for both Blue and Red. Category two (second page of graph set) displays the data by replication across the three possible COA's, again for both Blue and Red.



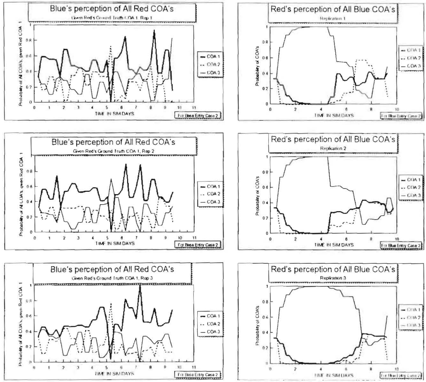
Tables H-1. R1-E1 Perception



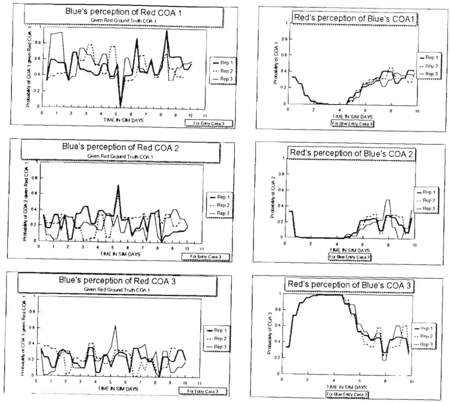
Tables H-2. R1-E1 Preceptions



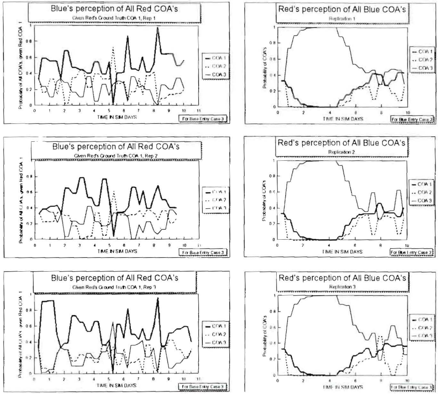
Tables H-3. R1-E2 Perceptions



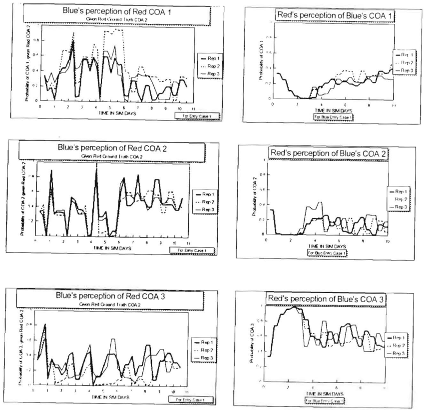
Tables H-4. R1-E2 Perceptions



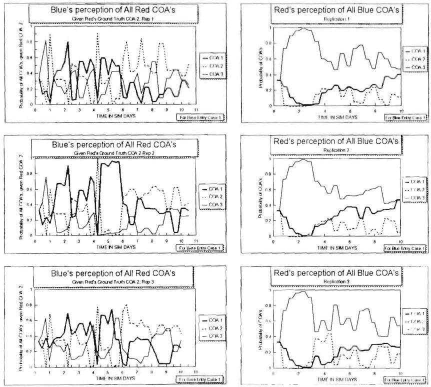
Tables H-5. R1-E3 Perceptions



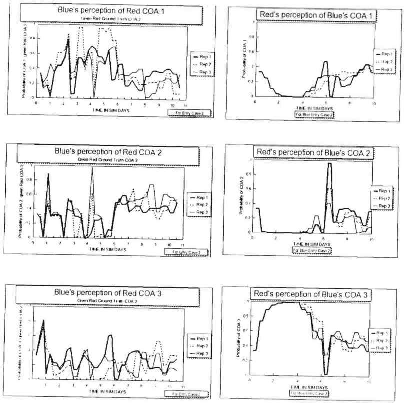
Tables H-6. R1-E3 Perceptions



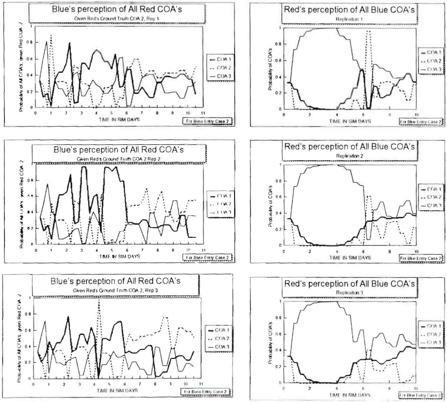
Tables H-7. R2-E1 Perceptions



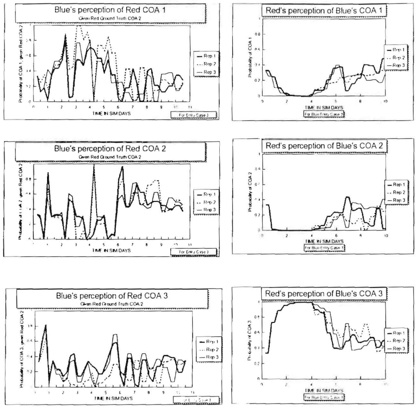
Tables H-8. R2-E1 Perceptions



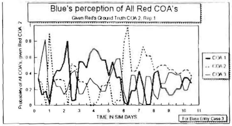
Tables H-9. R2-E2 Perceptions

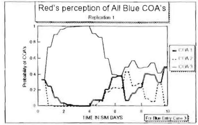


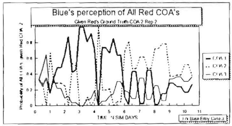
Tables H-10. R2-E2 Perceptions

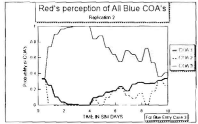


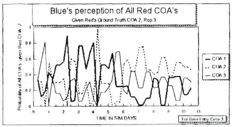
Tables H-11. R2-E3 Perceptions

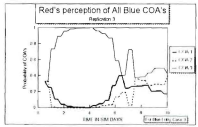




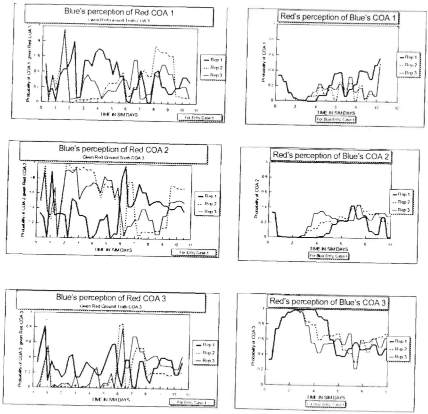




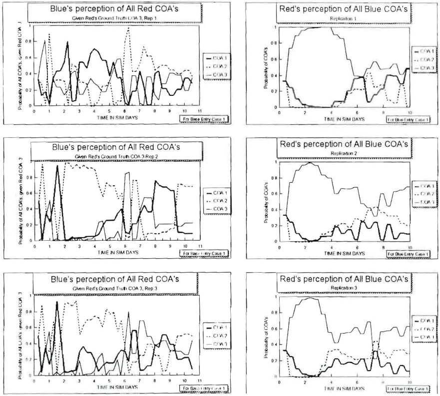




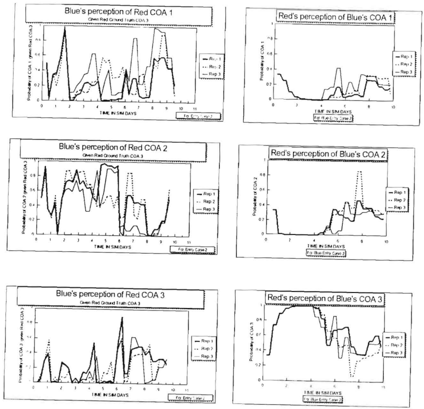
Tables H-12. R2-E3 Perceptions



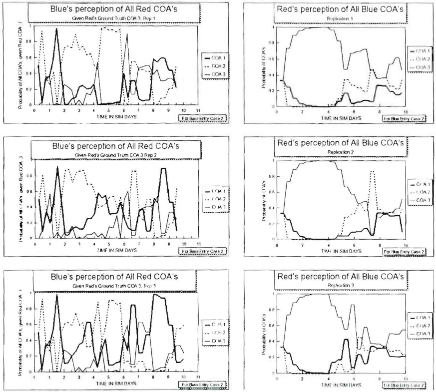
Tables H-13. R3-E1 Perceptions



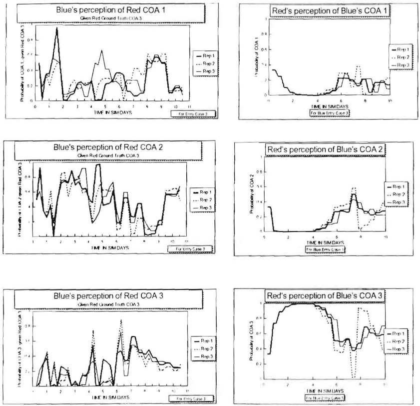
Tables H-14. R3-E1 Perceptions



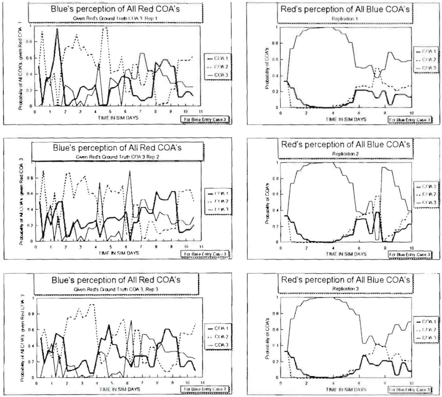
Tables H-15. R3-E2 Perceptions



Tables H-16. R3-E2 Perceptions



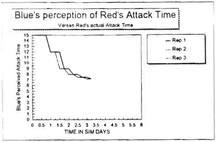
Tables H-17. R3-E3 Perceptions

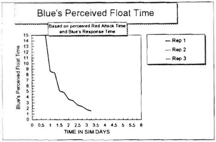


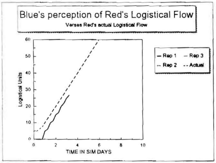
Tables H-18. R3-E3 Perceptions

APPENDIX I. LOGISTICAL GRAPHS

The graph sets are similar to the COA perception graphs. Each set contains four graphs. Within each set, the data were separated into four categories. Category one (first graph in set) displays the data corresponding to Blue's perception of Red's attack time across the three replications. Category two (second graph in set) displays the data corresponding to Blue's perception of the float time across the replications. Category three (third graph in set) displays the data corresponding to Blue's perception of Red's logistical flow across the three replications. Category four (fourth graph in set) displays the data corresponding to Blue's perception of Red's logistical rate across all replications.







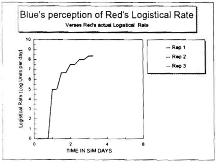
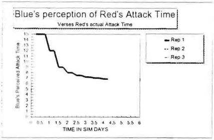
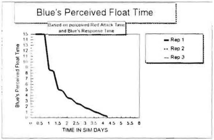
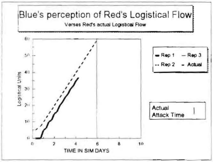


Table I-1. R1-E1 Attack Time







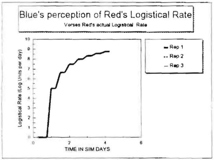
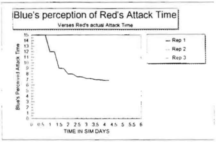
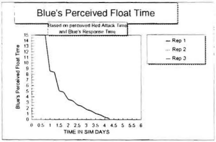
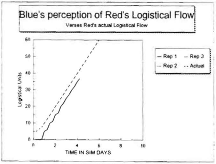


Table I-2. R1-E2 Attack Time







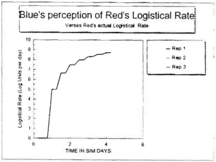
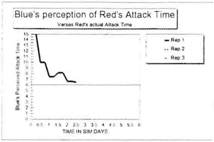
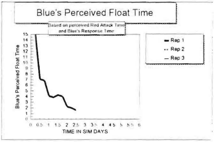
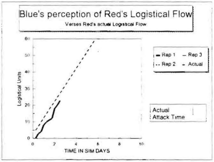


Table I-3. R1-E3 Attack Time







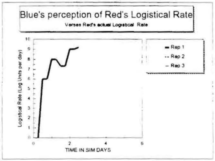
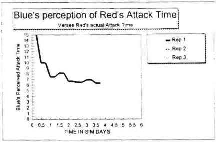
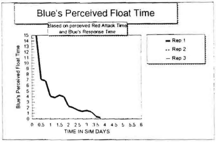
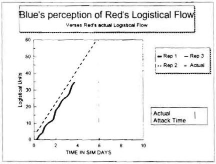


Table I-4. R2-E1 Attack Time







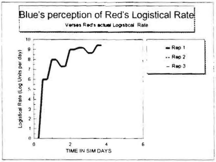
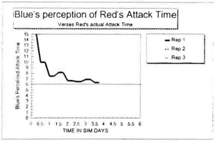
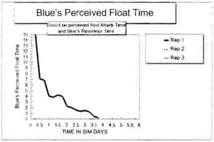
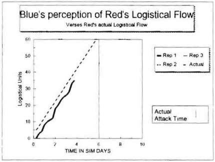


Table I-5. R2-E2 Attack Time







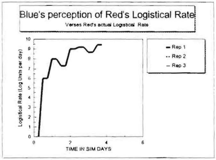
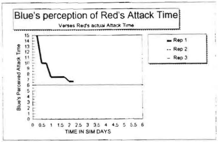
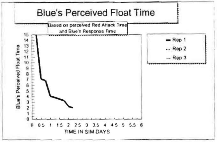
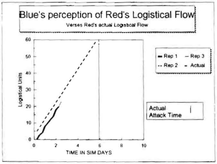


Table I-6. R2-E3 Attack Time







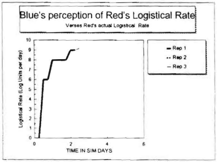
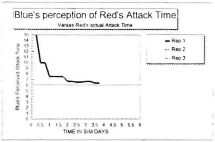
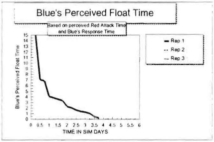
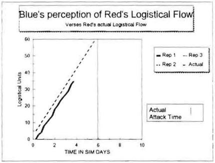


Table I-7. Attack Time







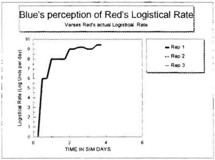
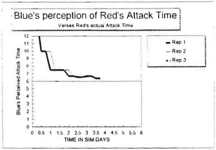
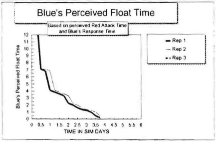
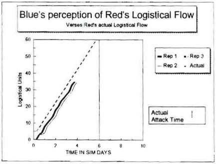


Table I-8. R3-E2 Attack Time







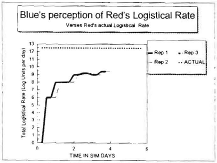


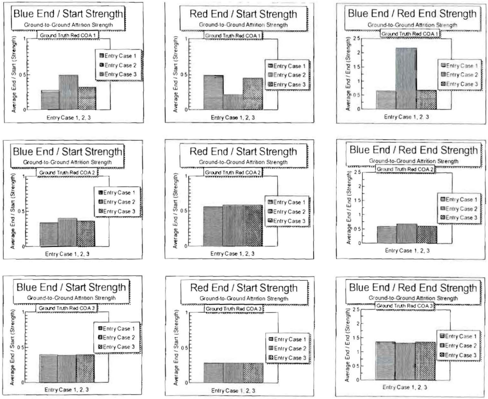
Table I-9. R3-E3 Attack Time

APPENDIX J. DATA FOR TRADITIONAL ANALYSIS

The graphs are grouped in sets, ground-to-ground attrition, logistics, and Personnel strengths. Each set has a data matrix and a corresponding table of graphs. The data matrices display the Red ground truth COA and MOE in the first column; and the outcomes, by entry case and replication, in the subsequent columns. The tables graphically display the data from the matrices. Each row of graphs is for a specific Red COA.

GROUND TRUTH RED COA 1															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance
(BLUE END STRENGTH) / (START STRENGTH)	0.3214	0.26	0.26	0.2805	0.0013	0.5119	0.4609	0.5001	0.491	0.0007	0.261	0.4119	0 299	0.324	0.0062
(RED END STRENGTH) / (START STRENGTH)	0.2785	0.5976	0.5976	0.4913	0.0339	0.2201	0.2201	0.2202	0 2202	8E-10	0.4768	0.4166	0.4769	0.4568	0.0012
(BLUE END STRENGTH) / (RED END STRENGTH)	1.1211	0.4225	0.4225	0.6554	0.1626	2.2587	2.0341	2.2064	2.1664	0.0138	0.5316	0.9604	0.6092	0.7004	0.0522
(B END STR / B START STR) / (R END STR / R START STR)	1.154	0.435	0.435	0.6747	0.1724	2.3251	2.0939	2.2713	2.2301	0.0146	0.5473	0.9886	0.6271	0.721	0.0553
GROUND TRUTH RED COA 2															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.2995	0.2995	0.4131	0.3374	0.0043	0.4319	0.3314	0.4348	0.3994	0.0035	0.3587	0.3579	0.3588	0.3585	2E-07
(RED END STRENGTH) / (START STRENGTH)	0.583	0.583	0.5223	0.5627	0.0012	0.5815	0.5814	0.5814	0.5814	2E-09	0.5828	0.5829	0.581	0.5822	1E-06
(BLUE END STRENGTH) / (RED END STRENGTH)	0.4991	0.4991	0.7684	0.5888	0.0242	0.7216	0.5537	0.7264	0.6672	0.0097	0.598	0.5965	0.5998	0.5981	3E-06
(B END STR / B START STR) / (R END STR / R START STR)	0.5137	0.5137	0.791	0.6062	0.0256	0.7428	0.57	0.7478	0.6869	0.0103	0.6156	0.614	0.6175	0.6157	3E-06
GROUND TRUTH RED COA 3															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.3921	0.3921	0.3922	0.3921	7E-10	0.3953	0.3976	0.3554	0.3827	0.0006	0.3921	0.3921	0.3922	0.3922	2E-09
(RED END STRENGTH) / (START STRENGTH)	0.2815	0.2814	0.2815	0.2815	1E-09	0.2816	0.2816	0.2815	0.2816	5E-09	0.2814	0.2815	0.2815	0.2815	1E-09
(BLUE END STRENGTH) / (RED END STRENGTH)	1.3533	1.3535	1.3534	1.3534	8E-09	1.3634	1.3714	1.2263	1.3204	0.0067	1.3536	1.3533	1.3535	1.3535	2E-08
(B END STR / B START STR) / (R END STR / R START STR)	1.3932	1.3933	1.3932	1.3932	9E-09	1.4035	1.4118	1.2624	1.3592	0.007	1.3934	1.3931	1.3933	1 3933	2E-08

Tables J-1. Ground-to-Ground Attrition Strength



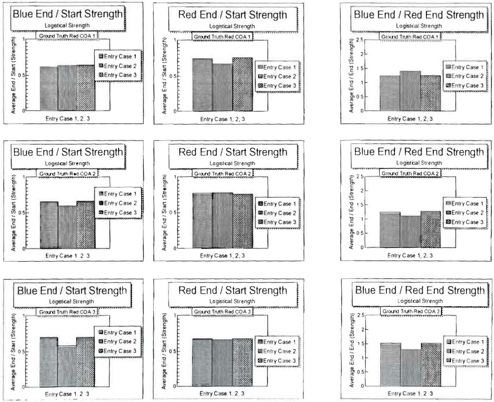
TABLES J-2. GROUND-TO-GROUND ATTRITION STRENGTH

GROUND TRUTH RED COA 1															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance
(BLUE END STRENGTH) / (START STRENGTH)	0.6374	0.609	0.6089	0.6184	0.0003	0.6455	0.6212	0.6455	0.6374	0.0002	0.6089	0.6981	0.6333	0.6468	0.0021
(RED END STRENGTH) / (START STRENGTH)	0.6552	0.7856	0.785	0.7419	0.0056	0.6748	0.655	0.6745	0.6681	0.0001	0.7818	0.7233	0.7591	0.7547	0.0009
(BLUE END STRENGTH) / (RED END STRENGTH)	1.4302	1.1398	1.1406	1.2369	0.028	1.4062	1.3945	1.407	1.4026	5E-05	1.1452	1.4191	1.2265	1.2636	0.0198
(B END STR / B START STR) / (R END STR / R START STR)	0.9728	0.7752	0.7758	0.8413	0.013	0.9565	0.9485	0.957	0.954	2E-05	0.7789	0.9652	0.8342	0.8594	0.0092

GROUND TRUTH RED COA 2															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.6332	0.6332	0.6979	0.6548	0.0014	0.5948	0.5967	0.5947	0.5954	1E-06	0.6594	0.6594	0.6594	0.6594	5E-10
(RED END STRENGTH) / (START STRENGTH)	0.7755	0.7761	0.7676	0.7731	2E-05	0.7914	0.7669	0.7906	0.783	0.0002	0.7437	0.7692	0.765	0.7593	0.0002
(BLUE END STRENGTH) / (RED END STRENGTH)	1.2004	1.1995	1.3368	1.2456	0.0062	1.1049	1.144	1.1059	1.1183	0.0005	1.3036	1.2604	1.2673	1.2771	0.0005
(B END STR / B START STR) / (R END STR / R START STR)	0.8165	0.8159	0.9092	0.8472	0.0029	0.7515	0.7781	0.7522	0.7606	0.0002	0.8867	0.8573	0.862	0.8686	0.0002

GROUND TRUTH RED COA 3															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.6937	0.6937	0.6938	0.6937	4E-09	0.5825	0.5824	0.5644	0.5764	0.0001	0.6937	0.6938	0.6939	0.6938	1E-08
(RED END STRENGTH) / (START STRENGTH)	0.6722	0.6721	0.6722	0.6722	2E-09	0.6486	0.6486	0.6714	0.6562	0.0002	0.6725	0.6719	0.6714	0.672	3E-07
(BLUE END STRENGTH) / (RED END STRENGTH)	1.5172	1.5175	1.5175	1.5174	3E-08	1.3203	1.3202	1.2358	1.2921	0.0024	1.5166	1.518	1.5195	1.518	2E-06
(B END STR / B START STR) / (R END STR / R START STR)	1.0319	1.0321	1.0322	1.0321	1E-08	0.898	0.8979	0.8406	0.8789	0.0011	1.0315	1.0325	1.0335	1.0325	1E-06

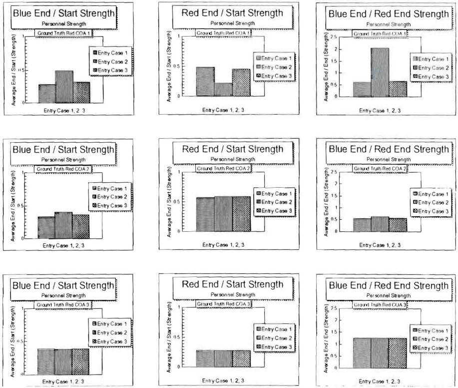
TABLES J-3. LOGISTICAL STRENGTH



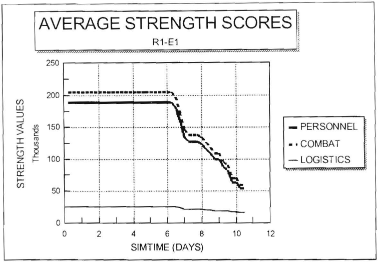
TABLES J-4. LOGISTICS STRENGTH

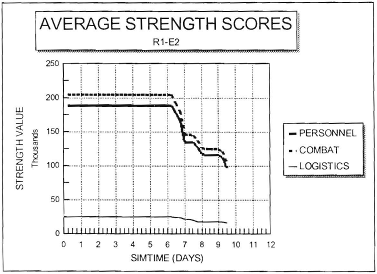
GROUND TRUTH RED COA 1															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance	REP 1	REP 2	REP 3	Average	Variance
(BLUE END STRENGTH) / (START STRENGTH)	0.3236	0.2611	0.2611	0.2819	0.0013	0.5134	0.4633	0.5012	0.4926	0.0007	0.2621	0.4092	0.299	0.323425	0.0059
(RED END STRENGTH) / (START STRENGTH)	0.2824	0.5995	0.5995	0.4938	0.0335	0.223	0.223	0.2231	0.223	3E-09	0.4771	0.4159	0.477	0.456675	0.0012
(BLUE END STRENGTH) / (RED END STRENGTH)	1.0669	0.4056	0.4056	0.6261	0.1458	2.1438	1.9348	2.0923	2.0569	0.0119	0.5116	0.9164	0.5837	0.670548	0.0466
(B END STR / B START STR) / (R END STR / R START STR)	1.1456	0.4355	0.4355	0.6722	0.1681	2.3018	2.0774	2.2465	2.2086	0.0137	0.5494	0.9839	0.6267	0.719994	0.0537
GROUND TRUTH RED COA 2															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.2995	0.2994	0.4105	0.3365	0.0041	0.4369	0.3349	0.4399	0.4039	0.0036	0.3606	0.3598	0.3607	0.36036	2E-07
(RED END STRENGTH) / (START STRENGTH)	0.5907	0.5908	0.5294	0.5703	0.0013	0.5894	0.5893	0.5893	0.5893	2E-09	0.5908	0.5909	0.5891	0.590246	1E-06
(BLUE END STRENGTH) / (RED END STRENGTH)	0.4721	0.4721	0.7222	0.5555	0.0208	0.6904	0.5293	0.6953	0.6383	0.0089	0.5685	0.5671	0.5702	0.568598	2E-06
(B END STR / B START STR) / (R END STR / R START STR)	0.5069	0.5069	0.7754	0.5964	0.024	0.7413	0.5683	0.7466	0.6854	0.0103	0.6104	0.609	0.6122	0.610527	3E-06
GROUND TRUTH RED COA 3															
		CASE 1					CASE 2					CASE 3			
	REP 1	REP 2	REP3			REP 1	REP 2	REP 3			REP 1	REP 2	REP 3		
(BLUE END STRENGTH) / (START STRENGTH)	0.3873	0.3873	0.3874	0.3873	1E-10	0.3982	0.4007	0.3563	0.3851	0.0006	0.3873	0.3874	0.3873	0.387351	2E-11
(RED END STRENGTH) / (START STRENGTH)	0.2847	0.2847	0.2847	0.2847	1E-09	0.2849	0.2848	0.2847	0.2848	5E-09	0.2847	0.2847	0.2847	0.284692	9E-10
(BLUE END STRENGTH) / (RED END STRENGTH)	1.267	1.2672	1.267	1.2671	1E-08	1.302	1.31	1.1656	1.2592	0.0066	1.2673	1.2671	1.267	1.267157	2E-08
(B END STR / B START STR) / (R END STR / R START STR)	1.3605	1.3607	1.3604	1.3605	2E-08	1.398	1.4066	1.2516	1.3521	0.0076	1.3607	1.3606	1.3605	1.360598	2E-08

TABLES J-5. PERSONNEL STRENGTH

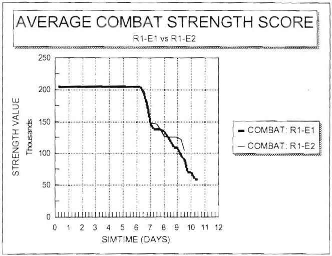


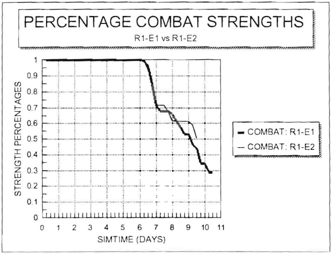
TABLES J-6. PERSONNEL STRENGTH





TABLES J-7. AVERAGE STRENGTHS OVER TIME





TABLES J-8. R1-E1 VS R1-E2 AVERAGE STRENGTHS OVER TIME

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